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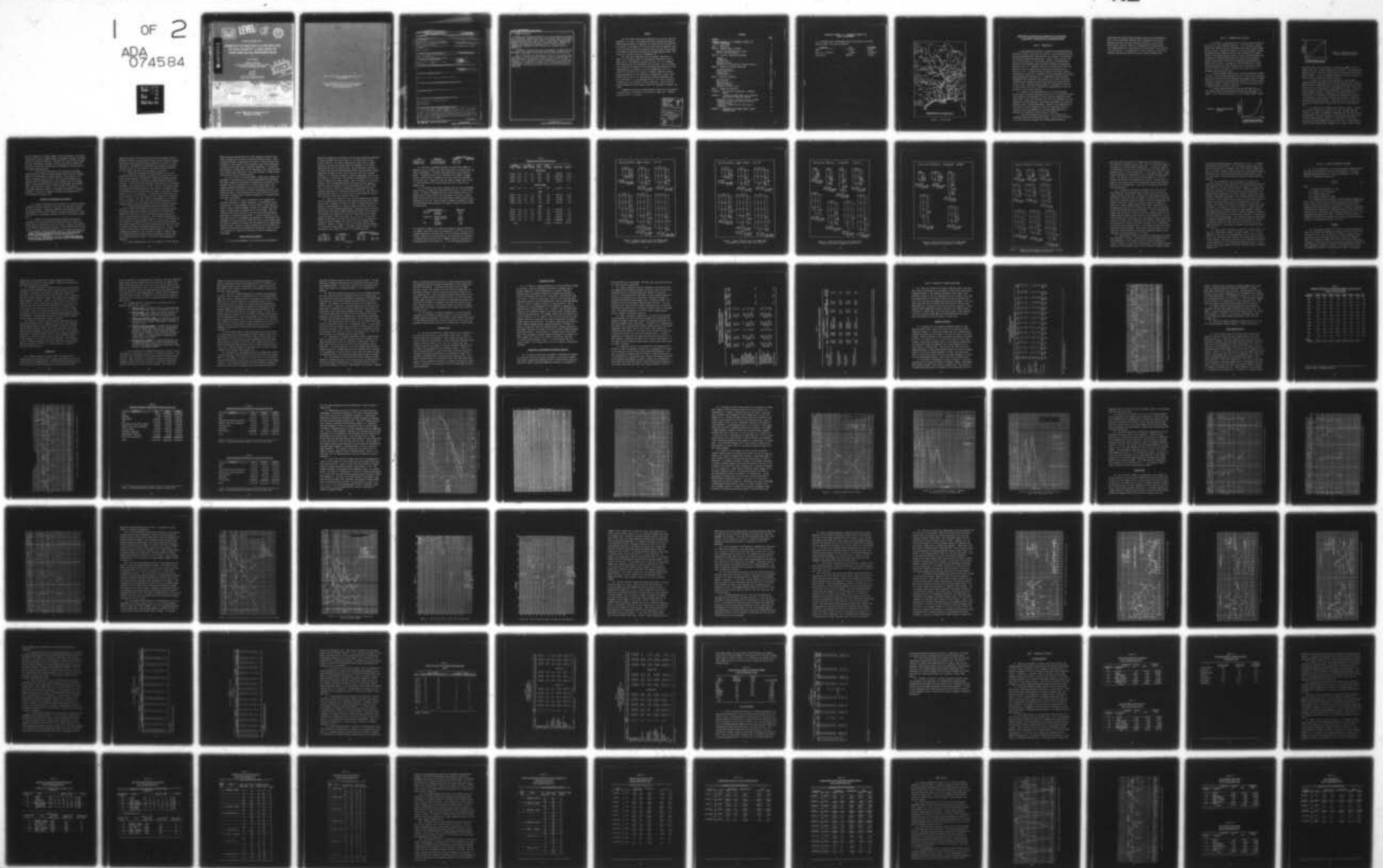

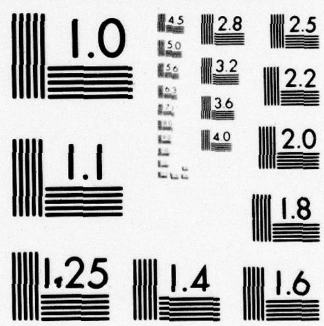

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TECHNICAL REPORT HL-79-11

SENSITIVITY OF BASE DATA IN THE ANALYSIS OF LOCK CAPACITY: A CASE STUDY OF LOCKS AND DAM 26, MISSISSIPPI RIVER

by

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July 1979
Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The replacement of Locks and Dam 26, Upper Mississippi River at Alton, Illinois, has been an extremely controversial project. One of the central points of this controversy is the capacity of these locks to process the traffic transiting this portion of the waterway system; the capacity is measured in tons of commodities moved by the tows passing through these locks. The determination of a capacity value for Locks and Dam 26 and adjacent locks is the subject of this report.

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20. ABSTRACT (Continued).

Methods of determining the capacity of a lock are discussed in the first part of the report. Consideration of all factors influencing a lock's capacity and the interrelationship of these factors are discussed. Based on this consideration and the interest shown in having an easy-to-apply, straightforward method for calculating lock capacities, a new methodology for computing lock capacities was developed and is presented herein. Results from such a computation are compared with those obtained using a simulation modeling approach.

An analysis of the basic data used in determining lock capacity from the most recent data available revealed some notable changes in characteristics of the traffic. This analysis is presented with significant differences noted.

Based on the latest data describing the traffic and lock operating characteristics, the capacity of Locks and Dam 26 is computed using the new computation methodology. The capacity was computed based on several different assumptions to test the sensitivity of the capacity values. It was found that the capacity is very sensitive to changes in the traffic characteristics and lockage timings. Capacities of adjacent locks on the Mississippi River were also computed. Data from locks on the Illinois River were not available in a usable form.

PREFACE

The work reported herein was undertaken for the Office, Chief of Engineers, U. S. Army. The current report was prepared to describe a methodology developed for computing lock capacities and the results of an analysis of the capacity of Locks and Dam 26 and the adjacent locks on the upper Mississippi River based on the most recent data available. This study was conducted from March 1977 through September 1978. This report was originally drafted in September 1977.

The study was accomplished under the general supervision of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and M. B. Boyd, Chief of the Hydraulic Analysis Division. Dr. L. L. Daggett, Math Modeling Group, was responsible for the study. Mr. T. D. Ankeny was a principal investigator in the development and application of the methodology and the analysis of the new lockage data. Mr. R. T. Garner III assisted in the coding of a computer program to execute the methodology and in the reduction of lockage data. Messrs. David Weekly and Ed Stone, U. S. Army Engineer District, Huntington, and Mr. Brad Fowler, U. S. Army Engineer District, St. Louis, assisted in obtaining and in the analysis of the lockage data. Messrs. Ed Cohn and Dick Thompson provided special advice and assistance throughout the study.

Commander and Director of WES during the study and the preparation and publication of this report was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
tons (force)	8896.444	newtons

Figure 1. Location map

SENSITIVITY OF BASE DATA IN THE ANALYSIS OF LOCK CAPACITY: A CASE STUDY OF LOCKS AND DAM 26, MISSISSIPPI RIVER

PART I: INTRODUCTION

1. Locks and Dam 26 (L&D 26) is located on the Mississippi River near Alton, Illinois, just below the junction of the Illinois River with the upper Mississippi River and just above the junction of the Missouri River with the upper Mississippi River. Figure 1 shows that the location of L&D 26 places it in a strategic position in the Mississippi River-Gulf Coast waterway system, the major waterborne transportation network of the U. S. Presently, there are two locks at this site; the main lock is 600 ft long and 110 ft wide and the auxiliary lock is 360 ft by 110 ft. Present observation indicates that these locks are reaching their capacity as is evidenced by the increasingly long waiting times experienced by passing tows. A replacement project has been recommended that involves the construction of a new dam 2 miles downstream from the existing site and would incorporate a single 1200-ft by 110-ft lock. Provisions would be made for including a second lock if later studies find this is desirable and authorization for the construction of this lock is obtained.

2. Because of the large estimated cost of this replacement project and the strategic importance of this lock to the growth of waterborne commerce, the replacement of these locks has stimulated a major controversy. Part of the controversy involves the determination of the capacity of the existing locks, the proposed replacement lock, and the adjacent locks in the waterway system. Because of the significance of this factor in the determination of when the replacement project is required, and in the computation of the anticipated benefits, an analysis of the capacity of these locks was conducted.

3. This report presents the results of this analysis and discusses points raised during the analysis. Since there was evidence of a need to provide a simpler, more straightforward method for

determining lock capacity than the approach used in the Design Memorandum 11, such a method was developed and is described in this report. Questions that were considered during this analysis effort included definitions of capacity, effects of changing locking operations and fleet characteristics on lock capacity, and sensitivity of lock capacity to various factors. A recomputation of the lock capacity of L&D 26 and adjacent locks was made based on the most recently available data.

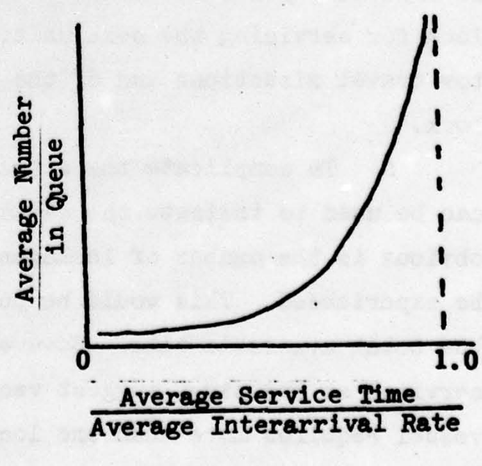
PART II: DETERMINATION OF CAPACITY

4. The task of sizing facilities is a basic problem that man has had to face in most investment decisions. It is therefore a classic problem that becomes even more significant when a major capital investment is involved. Navigation locks are in a general category of batch-processing service centers and as such can be analyzed as a queuing problem. The maximum physical capacity of such a processing center can be obtained by determining how many units (tows) can be processed during a given period of time and by knowing the characteristics of those units (tons/tow). The number of units processed can be determined by knowing how much time (locking time) is required to service the units (tows) and how much of the time the service center is available for servicing the units.

5. Queuing systems usually exhibit the following general characteristics. As the average interarrival rate of tows at the lock requiring service decreases and thus approaches the average service or processing rate of the lock, long waiting lines (queues) of tows will develop as shown in Figure 2 and lock utilization will increase rapidly until it reaches nearly 100 percent (Figure 3).

6. Several characteristics of locks and tows make the use of such simple relations just described more difficult than might first appear. First, the arrival pattern of tows is highly random in nature

Figure 2. Typical queue growth relation



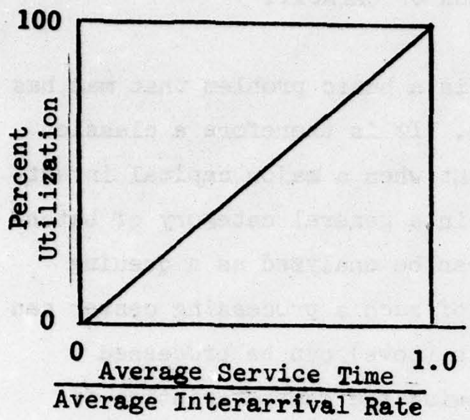


Figure 3. Typical unit service center utilization relation

unless the lock is in the vicinity of some control element, such as another lock, that is highly congested by tow traffic. Then the arrival pattern at the lock will be a direct function of the service rate of the control element. This is not typically the case and is not the case at L&D 26; thus tow arrivals are random in nature.

7. Secondly, the service time required for a tow is highly dependent upon the characteristics of the unit being serviced. Tows at L&D 26 are often larger than the lock facilities and must be broken into smaller units or be reconfigured to pass through the locks. This operation increases the service times considerably, causing them to have a broader random variation. In addition, the lock's service time is directional (i.e., different for upbound and downbound tows) and there is necessarily a certain amount of setup time required to prepare the lock for servicing the next unit. The setup time is also a function of tow travel directions and of the policies or rules for operating the lock.

8. To complicate the situation even further, a number of measures can be used to indicate the capacity of a lock. The most directly obvious is the number of lockages or chamberings per unit time that can be experienced. This would be purely a mean lockage time divided into the total available time. However, it is vessels that are being serviced so one might suggest vessels per unit time. In some cases, a vessel requires more than one lockage while in others, several vessels

may lock together in a single lockage. Since the purpose of the navigation locks is usually oriented toward the movement of commerce and since not all vessels carry commerce, a definition in terms of tows or barges per unit time might be desirable. Finally, since not all barges are full nor do they carry the same loads, the measure of tons per unit of time might seem appropriate.

9. In fact, since the purpose of the locks and the primary benefits from the locks are derived through reduced costs for shipping goods via the waterways, the primary measure of lock capacity is in terms of tonnage per unit of time. This introduces additional complexities into the determination of lock capacity since this tonnage must be related through the unit load/tow size/lockage time interrelations, the prediction of which is very difficult to accomplish. It does appear necessary, however, to determine lock capacity in terms of tonnage to relate this to impacts on commerce and shipping costs (or unit savings in shipping costs).

Methods for Determining Lock Capacity

10. A number of methods have been proposed in the past for determining the practical capacity of locks and can be generally described in three categories: analytical, graphical, and simulation methods. The graphical method is very similar to simulation modeling and is much more difficult to accomplish; therefore it has not really been utilized much.

11. Probably the best known and most widely used analytical techniques are those developed by Bottoms* and Davis.** These techniques have the advantage that they are simple to perform and therefore can be employed economically and quickly. These methods follow the very

* E. E. Bottoms, "Practical Tonnage Capacity of Canalized Waterways," Journal, Waterways and Harbors Division, Proceedings, American Society of Civil Engineers, Vol 92, Feb 1966, pp 33-47.

** J. P. Davis, "Tonnage Capacity of Locks," Journal, Waterways and Harbors Division, Proceedings, American Society of Civil Engineers, Vol 95, May 1969, pp 201-213.

simple description of the unit service process and basically involve defining an overall tow processing time and tow load, and then determining how many tows and hence how much tonnage can be locked in a fixed time period. The methods for determining the average tow processing time and load and for accounting for the chamber interrelations were not well defined when more than one chamber is available.

12. Simulation techniques have been developed over the past seven years that allow an analyst to determine the capacity of a lock facility and/or groups of facilities by simulating increasing traffic loads on the locks and the individual locking operations required to lock tows. As these loads are increased, the utilization of the lock(s) increases. This continues until a level of traffic is reached at which the waiting lines become excessively long or until a particular level of utilization of the lock facilities is reached. This level of traffic measured in tons is the capacity. In addition, such models will also yield a measure of how delay times and costs increase with increasing levels of traffic. This can be useful in determining a cost function for the utilization of a lock, thus allowing the determination of an economic capacity level that might be less than the physical capacity.

13. Lock and waterway simulation models are basically event processors. They create traffic from statistical frequency distributions using random draw techniques and process the resulting tows through the locks based on a set of defined operating policies and service time frequency distributions. These simulation methods have been successfully used for several cases in the past, and the models and the techniques for applying their results have been highly developed. These models operate with very basic and measurable data and can be used to analyze the effects of different operating policies. However, setting up the input data and calibrating these models is very time-consuming and expensive. Also, in order to develop a capacity value for a particular condition requires that the model be run many times with different levels of traffic. This also is time-consuming and expensive.

14. Early determinations of the lock capacity of L&D 26 used the

simple analytical methods while the latest analysis conducted by the Corps of Engineers was based upon simulation modeling results. While an attempt was made to demonstrate the effects of various factors that influence the lock capacity in the simulation study, there continued to be questions that would require additional simulations. In addition, there remained a strong desire to have available a more visible calculation procedure that would allow a more rapid response to questions that arise during the decision-making process.

15. As a result of this requirement, a method that combines the advantages of the analytical and simulation approaches was developed. This method computes lock capacities, assuming full utilization of the available time, by considering the tow fleet characteristics, the commodity movement requirements, and the lock service times. The analyst may modify any factor in the data describing the traffic, the processing times, or the locking policies so that impacts of errors or variations in measured data, different assumptions, or changing conditions may be determined.

16. There are, of course, limitations to the computational procedure used herein. A major limitation to its usefulness in the current state of the development is the fact that it only computes a capacity value (tonnage throughput) and does not determine any delay times or queuing values at varying levels of lock usage. This is a limitation that may be overcome in the near future with appropriate application of advanced queuing theory. A second limitation is that this method relies on the judgment and experience of the analyst in the assignment of the proportion of traffic that will use each chamber when more than one chamber is available and the chambers are of significantly different sizes. Finally, no direct influence of one lock facility on adjacent facilities can be determined by this process. Thus, if there is a potential for this kind of influence, it must be determined by other means.

Factors Affecting Capacity

17. One of the advantages of the newly developed computation

method for determining lock capacity over the older analytical approaches is that the effects of various factors on the capacity can be more directly observed. The earlier discussion on locks and their characteristics noted that the service times were dependent on the vessel characteristics and on the setup times. More specifically, tows that are larger than the lock when they approach the lock may require several chamberings through the lock to pass the entire tow; this is usually referred to as a multicut lockage or a double lockage when only two cuts are required. In some cases, the tow may be reconfigured to be fit into the lock chamber for a single lockage. This is referred to as a setover lockage if the reconfiguration must involve barges and the towboat or power unit and as a knockout if only the towboat must be moved. Whenever a tow must be broken or reconfigured, an extra amount of time (usually significant) is required for servicing the tow. Thus, the tow size/lock size relation is a critical value in determining the service time required and hence the capacity of the lock.

18. When a lock consists of more than one chamber and the chamber sizes are significantly different, the vessels must select which chamber will be used. Generally, the tows will select a chamber that will not require a reconfiguration or multicut lockage if possible, since this operation is time-consuming and hazardous. Therefore, smaller tows will usually choose the smaller chamber (generally referred to as the auxiliary chamber) when queues exist, while the larger tows use the larger (or main) chamber, even if they must wait. As the use of the larger chamber becomes heavy, those tows that require one or two breaks to go through the smaller chamber will tend to select that chamber rather than wait. However, in doing so, they will increase the time required to be serviced in that chamber. Lock chamber sizes available at locks referenced in this report are given in the tabulation below:

Lock	Waterway	Chamber Size, ft Main	Chamber Size, ft Auxiliary
Lock & Dam 25	Miss. River	600 × 110	
Locks & Dam 26	Miss. River	600 × 110	360 × 110
Locks & Dam 27	Miss. River	1200 × 110	600 × 110

(Continued)

Lock	Waterway	Chamber Size, ft Main	Auxiliary
LaGrange Lock	Illinois Waterway	600 × 110	
Lockport Lock	Illinois Waterway	600 × 110	

19. Tow size is generally expressed in terms of the number of barges in the tow; however, this can be deceiving as the barge sizes can differ significantly. The barge sizes generally in use are shown in Table 1. Therefore, the tow size, described as the number of barges per tow, and the type of lockage and the loads carried are dependent on the barge size. Figures 4-7 show the typical lockage types of various sized tows made up of typical barge types and for typical lock chamber sizes.

20. As mentioned previously, locking times will vary considerably with the type of lockage being performed and the size of the tow being locked. In addition, chamber setup time (time required by the lock in making ready to send the next tow) will depend on the type of vessel using the lock and the type of lock operating or chamber selection rule being used at the lock. Typical ranges of approach, chambering (including vessel maneuvering operations and chamber reversal), and exit times are shown below:

Lockage Component		Time, min
Approach	Exchange	10-25
	Turnback	2-10
Chambering	Single Straight	15-25
	Single Setover	25-35
	Double	60-90
Exit	Exchange	5-35
	Turnback	4-25

For sequential lockage of two vessels traveling in opposite directions, the chamber setup will involve an exchange exit by the first tow and an exchange approach by the second tow. For the successive lockage of two vessels traveling in the same direction, the setup time will consist of a turnback exit by the first tow, a chamber reversal or turnback and a turnback approach by the second tow. If the lock operating policy is

Table 1

Aggregated Barge Size Distribution

Barge Size	Barge Units	Draft Empty	Draft Loaded	Tons/ Barge	Number of Barges	Total Tons	Percent
			Open Hopper				
245×35	1.26	1.5	11.0	2400	204	489,810	2.14
195×35	1.00	1.5	9.0	1500	4576	6,864,720	30.03
175×26	0.67	2.0	9.0	1000	2408	2,407,575	10.53
120×30	0.53	1.0	7.0	400	977	390,800	1.71
			Covered Hopper				
195×35	1.00	1.5	9.0	1500	3861	5,791,400	25.32
			Deck				
200×50	1.47	1.4	8.0	1800	290	522,700	2.28
195×35	1.00	1.5	9.0	1500	430	645,570	2.83
150×32	0.70	2.0	6.0	500	677	338,600	1.48
100×26	0.38	1.3	6.0	350	1030	360,500	1.58
			Tank				
290×53	2.25	1.5	11.0	3000	551	1,653,085	7.23
240×50	1.76	2.0	9.0	2750	427	1,174,250	5.14
185×54	1.46	1.5	9.6	2100	310	651,400	2.85
195×35	1.00	1.5	9.0	1500	753	1,129,500	4.94
135×40	0.79	1.5	6.0	1000	440	440,461	1.94
Total					16,934	22,360,371	100.00

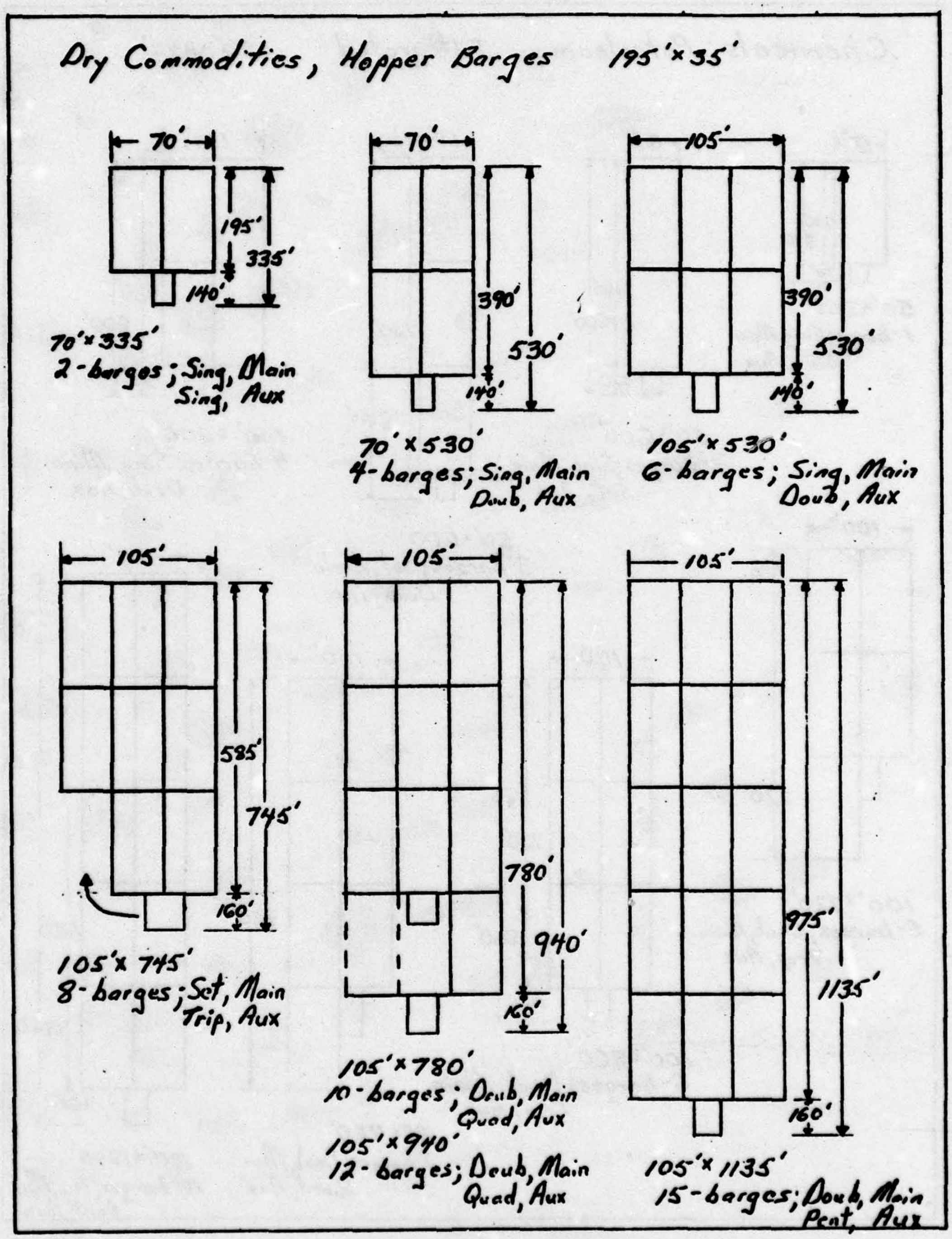


Figure 4. Typical flotilla sizes and lockage types; dry commodities, hopper barges, size 35×195 ft

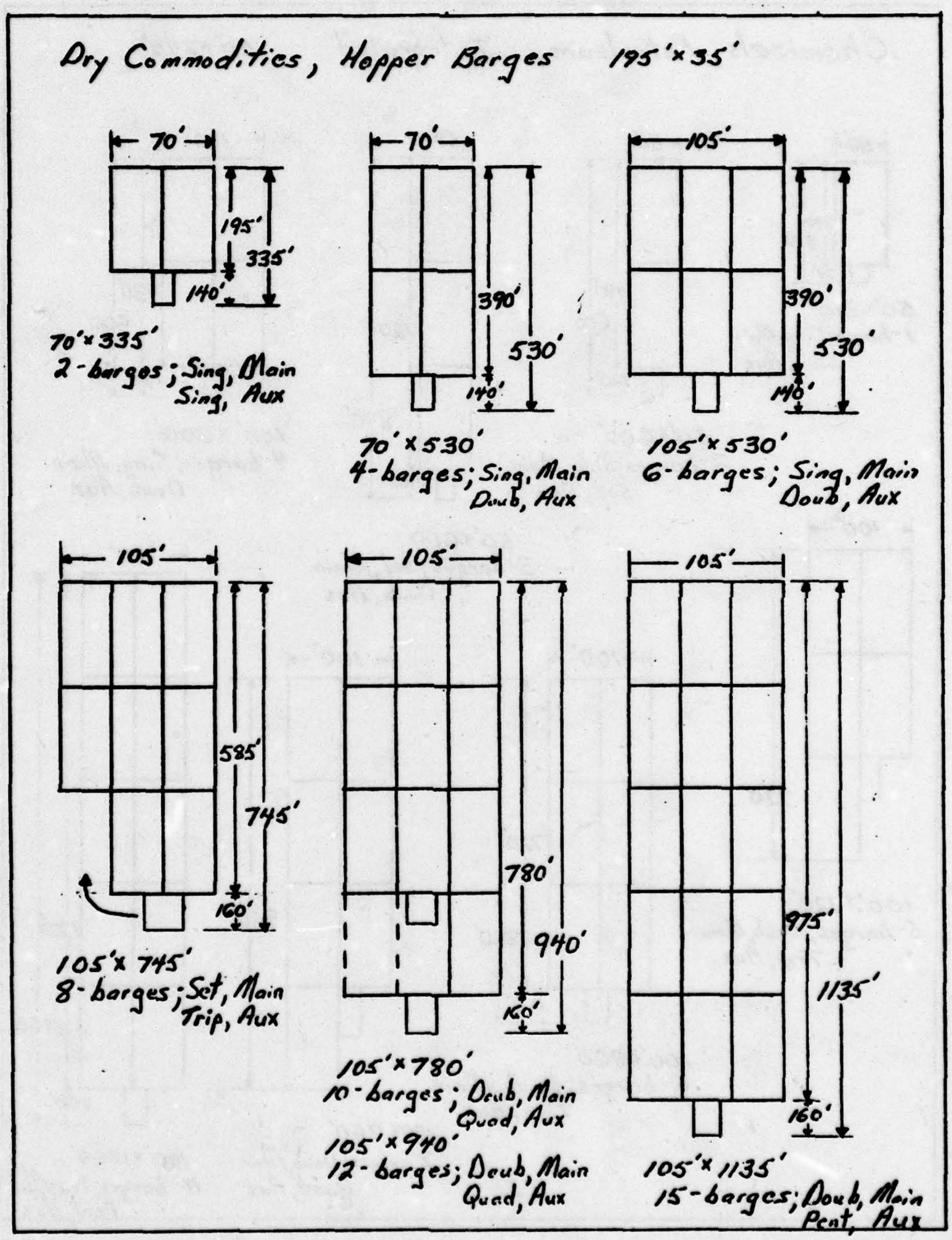


Figure 4. Typical flotilla sizes and lockage types; dry commodities, hopper barges, size 35×195 ft

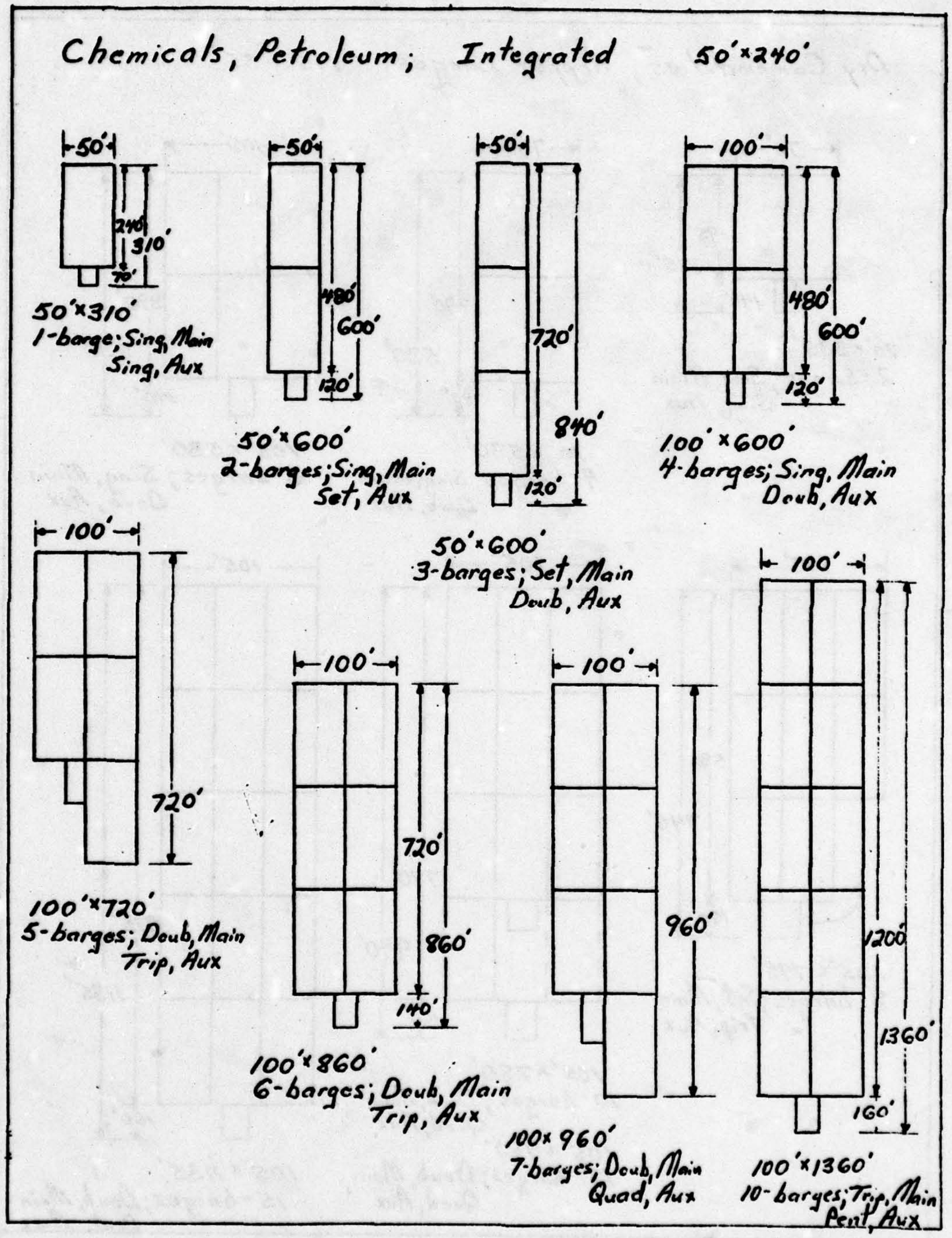


Figure 5. Typical flotilla sizes and lockage types; chemicals, petroleum; integrated, size 50×240 ft

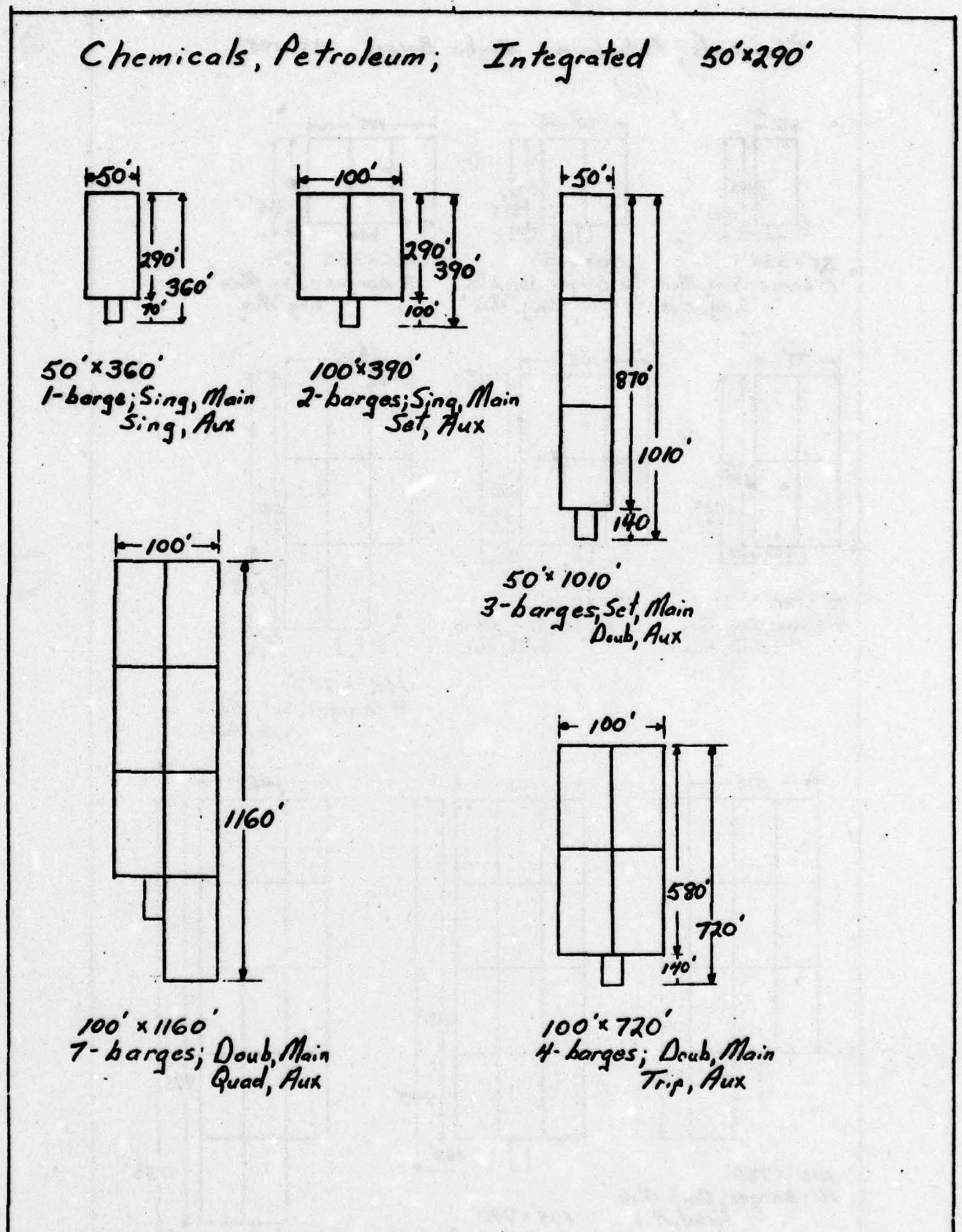


Figure 6. Typical flotilla sizes and lockage types; chemicals, petroleum; integrated, size 50×290 ft

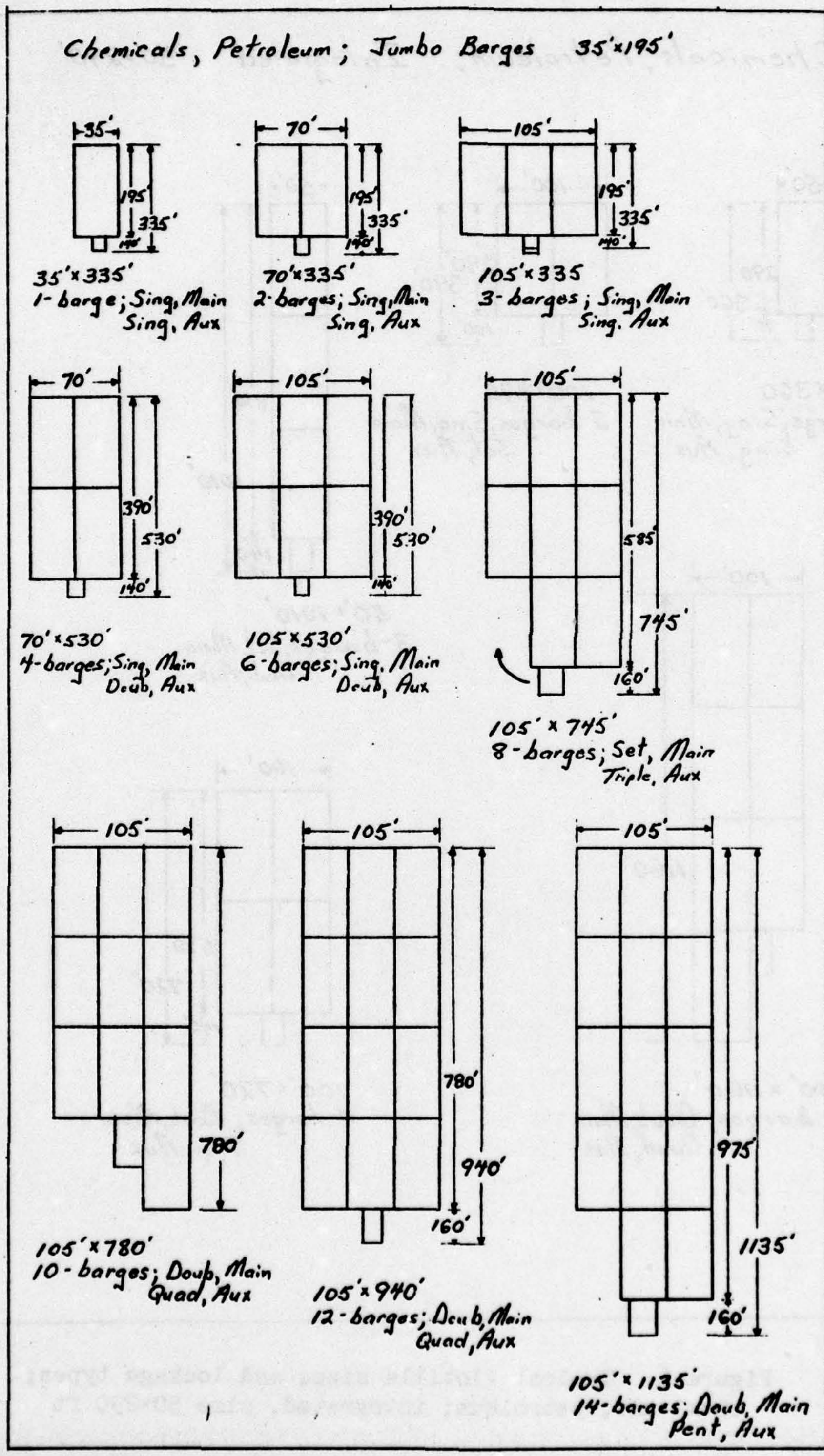


Figure 7. Typical flotilla sizes and lockage types; chemicals, petroleum; Jumbo barges, size 35×195 ft

such that tows are selected for lockage from the waiting lines in a First In-First Out (FIFO) pattern, then there is a fifty-fifty chance of an exchange or turnback approach taking place. If the policy applied is a Flip-Flop, or lock one in one direction then one in the other, all approaches will be of the exchange type. In some cases, there is a particular advantage in locking several tows in the same direction sequentially. For example, a selection rule may be applied to lock four upbound tows and then four downbound ones (4U-4D). In this case, one quarter of the setups would be of the exchange type and three quarters would be of the turnback type. These rules can influence the service times significantly.

21. In addition, the method of breaking tows to fit into the lock chamber and for refleeting them to depart the lock area can influence the mean service time. Presently, most tows requiring reconfiguration to lock, enter the lock chamber to break down or re-form and then refleet partially inside the chamber, using the exiting guide wall. However, tows can be required to be ready to enter the chamber for service as a single lockage (Ready-to-Serve (RTS)) if facilities for refleeting away from the lock vicinity and a power unit for moving unpowered cuts through the locks are available. A third procedure would require that provisions be made for the tow to refleet outside the lock chamber along the guide wall but still be in the chamber area. In the latter method, the tow refleets in the lock area but clear of the gates so that the chamber can be reversed to lock another tow traveling in the same direction as the first tow, while the first tow is reconfiguring to leave the lock (Industry Choice). An entering tow would still break down inside the lock chamber. This policy is only effective if it is used with a selection policy involving the sequential lockage of tows traveling in the same direction, e.g., 4U-4D.

22. Several other factors can influence significantly the service time required to lock tows. These generally vary considerably and are not controllable. One of these is the lift required between pool levels. Generally, as the lift increases there is an increase in service times due to the increased volume of water that must be passed through

the filling and emptying system. Another factor is ice. Ice affects the service time in two ways: (a) it increases the time required by tows to enter and exit the chamber, and (b) it requires lockages with only ice in them. Finally, current conditions in the approach channels can be such that tows have great difficulty in maneuvering into and out of the locks. This will generally increase the mean service time required.

23. Since tonnage is used as the measure of capacity for commercial navigation locks, analysis of the relation between tons, the tows required to move the tonnage, and the lockages and service times required to process these tows is required. Commercial movements vary with time, the degree of that variance and the directionality of the movements being dependent on the type of commodity being moved and the economic or marketing environment. This variance with time is significant since a lock's capacity may be reached for certain peak periods of movement while other times of the year movements may be less than capacity. The spatial distribution of movements is significant in that an imbalance of movements in the two directions of travel through the lock will require a balancing movement of empty equipment (barges). Some commodity types require the use of special equipment or otherwise have special requirements that demand return movements of equipment that are empty (dedicated equipment). The temporal and spatial distribution of commodity movements at some locks (particularly L&D 26) combine to be especially significant when a portion of the traffic (e.g., the upper Mississippi) is lost when the waterway closes during the winter (ice) season.

24. Other factors affecting the capacity of a lock include lost time due to maintenance, repairs, accidents, weather, etc. If two chambers are such that tows cannot approach, exit, or use one chamber while a tow is using the other chamber, lost locking time will result in both chambers. The same is true when separate lockages are required to lock noncommercial or noncommodity-carrying vessels (e.g., recreational craft, light commercial towboats, passenger vessels, government vessels, etc.).

PART III: CAPACITY COMPUTATION PROCEDURE

25. A brief explanation of the newly developed computation procedure used in this analysis of L&D 26 is presented here. A more detailed step-by-step procedure is provided in Appendix A. The basic formula for computing the capacity is:

$$C = \frac{T_A}{T_L} L_T S \qquad (1)$$

where

C = physical lock capacity, in tons

T_A = available time for locking

T_L = average lockage time

L_T = average tonnage per lockage

S = seasonality factor applied to obtain the annual tonnage value

Each of these variables must be determined considering the stochastic nature of each and accounting for the interdependence that exists between tow sizes and loads and locking times. Generally, the required distributions are obtained from observations made of actual traffic at the lock sites. These data are collected and recorded as a part of the Performance Monitoring System (PMS). Observations used in earlier studies were obtained from a special data collection system established by the U. S. Army Engineer District, St. Louis.

Tonnage

26. The tonnage movements that require tows to pass through the locks are basically what determine the amount of traffic trying to be serviced by a lock. The distribution of tonnage by commodity type is allocated to the various barge types used to carry each commodity. Based on the amount of tonnage that can be carried by each barge type, the degree of dedication and the required empty movements to balance the barge movements, the number of barges of each type required to move the tonnage are computed. By multiplying the number of each type of

loaded barge by the average load per barge, summing the resulting tonnage, and dividing by the total number of barges, the weighted average load per barge may be obtained.

27. Now that the number of barges required to move the specified tonnage has been determined, they must be transformed into tows so that the number of lockages and the number of barges per lockage can be determined. This together with the average weighted load per barge will yield the average tonnage per lockage. The barges may be considered as being assigned to tow types. These tow types have been considered as being made up of common sized barges, although they do not have to be limited in this way. Based on the distribution of the barge types to the tow types, the observed tow size distribution in terms of barges per tow and the type of lockage required by each size tow, the number of lockages of each tow type and the weighted average barges per lockage are determined. By multiplying this value by the previously computed tons per barge, the tonnage per lockage is obtained.

28. Two sets of records are available for determining the tonnages passing through locks. Lockmaster records are used in determining the average loads per barge while tonnages reported to the Waterborne Commerce Statistics Center (WCSC) are often used in describing annual tonnage movements up and down through the locks. The lockmaster records must be used because WCSC does not report tonnage movements by barge type. Lockmaster records in the St. Louis District typically record tonnages 3 to 4 percent larger than WCSC data. This difference is due to rounding tonnages at the locks, whereas more precise waybill data are furnished to the WCSC. A correction factor is applied to account for this variance.

Lockage Time

29. Average lockage (or service) time is a function of the lockage type and the locking policy. Lockage time consists of the lock setup time and the chambering time. The lock setup time consists of the time for the tow to approach and exit the lock and the time for the

lock to be reversed, if this operation is necessary. The lock chambering time includes the time required for the tow to enter the chamber, the gates on the entering side to close, the lock to fill or empty, and the gates on the exiting side to open. If a tow reconfiguration is required, this will take place during the chambering and/or exit operations. If a tow requires two or more chamberings for lockage, then the chambering time will include the time to break the tow, to extract the unpowered cut of the tow, to reverse the lock, to lock the second cut, and to remake the tow.

30. Lockage types are classified for this analysis into five general classifications. These are:

- a. Single lockage. A lockage in which a tow can enter the lock and be processed with no reconfiguration of the tow.
- b. Double lockage. Any lockage of a tow that requires the tow to be uncoupled at barge interfaces so that two separate chamberings are required to process the tow.
- c. *Triple cut or greater lockage.* Any lockage of a tow that requires the tow to be uncoupled at barge interfaces so that three or more separate chamberings are required to process the tow.
- d. Setover or knockout lockage. A lockage that can be performed with one chambering if the tow is reconfigured. A knockout lockage only requires the uncoupling of the towboat and the movement of this towboat to another position in the chamber so that the tow may fit entirely in the chamber. A setover lockage requires that the towboat and one or more barges must be uncoupled and repositioned in the chamber.
- e. Multiple vessel lockages. A lockage that requires only one chambering operation to service more than one tow. A separate approach and exit time is required for each vessel in the lockage, although these vessels may overlap the use of the approach channel.

31. As noted above, the lockage time required to service a tow is influenced to a large degree by the type of lockage taking place. Lockage time is also influenced by the tow processing policy being used at the lock. Under the normal or "standard" processing procedures used presently at most locks, tows are allowed to uncouple or break into separate cuts and to re-form in the lock chamber. The entire lock

chamber is usually occupied during such a reconfiguring operation. A winch is often used to extract the unpowered cut(s) of a multicut tow. The winching operation must be performed slowly to keep such a large mass under control. Several alternatives are available to reduce time lost due to this operation.

32. The first of these alternatives is presently being employed at L&D 26. This is called the "Industry Choice (IC)" operating policy. Under this policy, a separate towboat or switchboat will extract the unpowered cut of a double lockage or a reconfigured setover tow to a point where the tow will clear the lock gates during reconfiguration. At L&D 26, this was accomplished by extending the upper guide wall of the main chamber so that adequate length was made available for this purpose. The lower guide wall was of adequate length. To make this policy effective, a series of tows traveling in the same direction must be locked sequentially so that the lock chamber can be reversed and the next tow approach and enter the lock while an exiting tow is reconfiguring. Efforts are made to select a single lockage tow as the last in the series so that no reconfiguring is required for the last tow and the exchange to locking tows in the opposite direction may proceed immediately.

33. The second method for improving lockage times requires that all multilockage tows be reconfigured as single lockages before call-up. For example, the two portions of a double lockage tow are locked consecutively with the tow uncoupling and reconfiguring operations taking place outside the vicinity of the lock. This requires mooring facilities for these operations and assist boats to power the extra portions of the tow. Multicut lockages are considered to be a series of single lockages with a turnback setup between cuts.

34. In addition to the chambering time, the lockage time includes the lock setup time. This involves a tow's exit from the lock, turning back the lock chamber to be ready for the next tow, if it is traveling in the same direction as the exiting tow, and the approach of the following tow. If two tows are traveling in the same direction, normally the second tow to be locked can approach the lock to some point near the

gates and the approach time for such an entry will be short. For tows traveling in opposite directions, the tows must pass each other in the lock approach channel. In this case, both the exit and approach will involve the transit of the approach channel, i.e., a long exit and approach.

35. The tow selection policy used at a lock to determine the next tow to be locked will have a significant effect on the locking time. The order of tow call-up will determine the sequence of lock setup operations required, each of which requires different periods of time to complete. For example, in an FIFO policy, each tow is locked in the order of arrival. There is a 50 percent chance that the next tow to be locked will be traveling in the opposite direction of the current tow being locked, thus requiring an exchange type setup. Likewise, there is a 50 percent chance that the next tow will be traveling in the same direction, thus requiring a turnback setup. The FIFO policy generally minimizes both the delay time experienced by tows and the queue sizes.

36. The normal policy used at locks is a 1 Up-1 Down (1U-1D) type policy or a Flip-Flop policy, as it is sometimes called. In this policy, the first tow in the waiting line in the pool for which the lock is set to serve is selected. After lockage of that tow is completed, the next tow selected is the first tow in line in the opposite pool. Thus, this policy results in an exchange setup for every lockage.

37. When there is a distinct advantage in using a turnback type setup, a locking policy that will produce a series of lockages in the same direction would result in a reduction of locking time, Thus, a policy that would lock N tows up, then N tows down (NU-ND) would be beneficial. In such an operation, N-1 of the lockages would involve a turnback setup and 1 lockage would involve an exchange setup. Normally, in such operations, tows are forced to wait longer than under any other tow selection policy, thus queues and average waiting times are larger.

38. The procedure for determining the average locking time must therefore be determined based on the locking policy, the distribution of tow sizes (and hence lockage types), and the distribution of tows to lock in each chamber of a dual or triple chamber lock facility. Average

times for exchange approaches and exits, turnback approaches and exits, and chambering times are available through PMS for each lockage type, direction, and chamber. In addition the average time for chamber reversal is given. The chamber setup time for each lockage type is determined according to the tow selection policy and is added to the lock chambering time. Then the weighted average locking time for each chamber is computed based on the distribution of tow sizes (and hence lockage types) assigned to the chamber by multiplying the average lockage times by the number of lockages of each type and dividing by the total lockages occurring. This process assumes that there is always a waiting line in each pool of sufficient size to fully enforce the tow selection policy.

39. No procedure is currently implemented to allow the direct computation of multivessel lockage times and to reduce the number of lockages required accordingly. The effect of such lockages is accounted for by manually modifying the tow size distribution so that large tows represent several smaller tows that are combined into a single lockage.

Available Time

40. The time available for lockage operations will generally be less than the total time in a period under consideration. Several factors reduce the time available. These include time when the lock cannot be used due to maintenance or repair work being conducted on the chamber, accidents, weather (e.g., fog, ice, or wind) that stops traffic, and use of the chamber for locking lightboats (towboats with no barges), and governmental and recreational vessels. Based on a lock's operating history, a given percentage of the total time period that may be considered unavailable due to maintenance, repair work, accidents, and weather must be subtracted from the total time. Also, based on observed times for processing vessels other than tows and the number (either estimated or observed) of lockages involving only these vessels, a reduction in the available time for locking commercial tows may be determined.

Seasonality Factor

41. In practice, tonnage movements do not occur uniformly throughout the year. There are frequently variations in shipments due to seasonal demands for certain commodities or to market conditions. Secondly, there are physical factors that influence the movement of goods on the waterway, such as low- or high-water conditions and icing on the river. At L&D 26 in particular, there is a very definite shipping season related to the three-month period when the upper Mississippi River is closed to navigation because of icing conditions. This is accounted for in the determination of lock capacity by computing the capacity during a typical period (e.g., a month), then multiplying that tonnage by the average percentage of the annual traffic normally found to move during that period. For example, suppose that the capacity of a lock was computed to be "x" number of tons per month and that the input tonnage levels used in deriving this capacity represented the maximum monthly traffic during the year. The annual tonnage capacity would not be the computed maximum monthly tonnage multiplied by 12 (number of months in a year) but rather the maximum monthly tonnage multiplied by some number less than 12 in order to allow for reduced tonnage movements during other months. This multiplier is computed solely from a knowledge of the percentage of annual tonnage represented by the maximum (or other tonnage level) used in the capacity calculations, such that $Y = 100/\%$ of annual tonnage , where Y is the multiplier and "% of annual tonnage" is the tonnage level used in the capacity computational procedure.

Comparison of Calculated and Simulated Capacity

42. In order to verify this new method of computing the capacity of a lock and to provide a greater confidence in the results obtained from using a computerized simulation model to determine the capacity of L&D 26, 25, and 27, a detailed comparison was made of the capacity of

L&D 26 determined by both methods. The same basic input data were used as a basis for these comparisons.

43. Table 2 presents a detailed comparison of the results from the computation and simulation methods for L&D 26, using the 1972 fleet characteristics for the FIFO-Standard and FIFO-RTS tow selection policies. No adjustments have been made of either computed capacities to allow for recreation craft, lightboats, maintenance, weather, or deviations between WCSC and lockmaster data. As shown in Table 2 the values of the various parameters computed agree very well. The major deviations are in the auxiliary chamber computations where the percent differences are greater due to the smaller absolute values of the parameters. The general agreement of the total annual tonnage capacity within 3 percent is considered very good.

44. Table 3 presents a comparison of the capacities determined by both methods, this time including adjustments for recreational and lightboat lockages, maintenance, weather, and tonnage corrections for WCSC and lockmaster report differences. Included in this comparison are the present locks operating under standard and RTS policies, the single replacement lock (1200 ft long by 110 ft wide), L&D 25 under both standard and RTS, and L&D 27. All cases are for the FIFO tow selection policy and are based on the 1972 fleet characteristics. A similar comparison is included for the large fleet characteristics used in the DM11 analysis to determine the effect of tow size on lock capacity. In all cases, the lock capacities agree within 6 percent and in most cases are within 3 percent.

45. Therefore, based on the similarities in the capacity determination of these two methods, a great deal of confidence can be placed in the capacities derived using the new computational approach. However, the reader is reminded that the effects of delays and queues are not accounted for in this process; thus different tow selection policies could influence the comparative results. Results of the comparisons also verify the conclusions reached in DM11 concerning the capacities of the several locks that were used in the economic analysis of L&D 26.

Table 2

L&D 26 Comparison of Simulation Model and

New Computational Technique Results

	Main Chamber			Auxiliary Chamber			Total		
	Simu-lated	Com-puted	% Diff	Simu-lated	Computed	% Diff	Simu-lated	Com-puted	% Diff
Lockage Types									
Single	18.0	22.0	+4	43.0	42.0	-1			
Setover	23.0	24.0	+1	9.0	14.0	+5			
Double	58.0	53.0	-5	44.0	37.0	-7			
Triple	1.0	1.0	0	4.0	8.0	+4			
FIFO-Standard									
Barges/Tow	8.62	8.80	-2	3.53	3.13	-11			
Barges/Lockage		5.70	--		2.60	--			
Tons/Barges	968.0	977.7	-1	968.0	977.7	-1			
Time/Lockage	58.11	60.5	+3	45.45	47.06	+3			
Lockages/Month	743.0	719.0	-3	950.0	918.0	-3			
Tons/Month	3.881	4.009	+3	2.118	1.849	-13			
Tons/Year	41.0	42.1	+3	22.4	19.4	-13			
Total Tons/Year							63.4	61.5	-3.0
FIFO-Ready-to-Serve									
Barges/Tow	7.72	8.80	14	2.84	3.13	+10			
Barges/Lockage	5.24	5.70	+9	2.21	2.06	-7			
Tons/Barges	968.0	977.7	-1	968.0	977.7	-1			
Time/Lockage	44.96	47.45	+6	36.93	38.84	+5			
Lockages/Month	961.0	910.0	-5	1170.0	1112.0	-5			
Tons/Month	4.839	5.074	+5	2.486	2.24	-10			
Tons/Year	51.2	53.3	+4	26.3	23.5	-10			
Total Tons/Year							77.5	76.8	-0.9

Table 3

Comparison of Capacities - Simulated and Computed

Lock	Fleet	Locking Policy: Tow Selection	Locking Policy: Tow Processing	Capacity: Simulated	Capacity: Computed	Percent Difference
L&D 26 Present (600'×100';360'×110')	1972	FIFO	Standard	58.1	57.8	0.5
	1972	FIFO	Ready-to-Serve	73.0	72.2	1.1
	Large	FIFO	Ready-to-Serve	78.8	78.1	0.9
L&D 26 Replacement (1200'×110')	1972	FIFO	Standard	85.7	85.5*	0.2
	Large	FIFO	Standard	111.4	114.4*	-2.7
L&D 25 Present (600'×110')	1972	FIFO	Standard	38.9	37.8	2.8
	1972	FIFO	Ready-to-Serve	45.4	42.9	5.5
	Large	FIFO	Standard	55.2	51.8	6.2
L&D 27 Present (1200'×110';600×110')	1972	FIFO	Standard	147.6	141.6*	4.1
	Large	FIFO	Ready-to-Serve	172.1	161.9*	5.9

* Computations involved modifying the tow size distribution to account for chamber packing (multivessel) locking operations.

PART IV: ANALYSIS OF EXISTING CONDITIONS

46. Since the release of the Corps of Engineers DM11, there has been a major controversy over the capacity of the present locks and the estimated capacity of the proposed replacement locks. Many of the differences center on the lock operating policies in effect at the locks and characteristics of the traffic using the locks, particularly the size of the tows and the average loads carried by the barges. Since the basic input data used in the DM11 study were based on 1972 tow fleet characteristics, an analysis of more recent data was conducted to determine any major changes that may have occurred in the traffic characteristics or locking times. Since the earlier study, a more extensive lock data collection system PMS has been implemented and this data source was primarily used as the basis for this study.

Commodity Movements

47. A comparison of the commodity movements passing through L&D 26 revealed a major shift in the relative distribution of these commodities (Table 4). During the calendar year 1976, downbound grain movements had grown from 42.5 percent to become 52 percent of the total tonnage. Upbound movements of coal, petroleum, and chemicals decreased from 15.2, 14.5, and 11.7 to 8.3, 10.2, and 8.5 percent of the total tonnage, respectively--the major impact of this being an imbalancing of the upbound and downbound movements from a nearly balanced ratio of 49/51 percent to 39/61 percent. Thus, during 1976 there was a much higher percentage of empty barge movements required to bring the barges upriver to move the increased shipments of grain. This also had an effect on the observed size of tows as these grain movements took place in tows containing more barges. This effect will be observed later.

48. The effect of seasonality is shown in Figure 8. Note that regular dips occur during the months of December, January, and February and sometimes in March. This effect is largely due to the closing of the upper Mississippi River to navigation in the winter when the river

Table 4

Monthly Distribution of Traffic by Commodity

Lock and Dam 26, Year 1976

Commodity	Direction	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg	1972 DM11
		Percentage of Month's Tonnage for 1976													
Corn, soybeans, and grain	Up	--	--	1.3	--	1.3	--	1.5	--	1.5	1.4	1.4	--	--	3.0
	Down	56.6	59.2	51.4	54.5	54.0	54.7	56.1	46.6	42.3	44.0	53.6	51.2	52.0	42.5
Coal	Up	3.9	4.7	10.6	11.9	9.2	8.1	8.0	8.3	13.5	11.3	6.1	4.3	8.3	15.2
	Down	--	--	1.1	--	--	--	--	--	--	--	--	--	0.09	--
Petroleum	Up	9.1	6.7	8.3	7.9	10.2	10.2	10.7	11.5	12.5	10.4	10.1	15.3	10.2	14.5
	Down	3.2	2.5	4.1	2.3	2.7	2.3	2.7	3.4	2.6	2.2	1.3	2.4	2.6	1.1
Gravel, sand, and aggregate	Up	--	--	--	1.2	--	1.0	--	1.7	1.7	1.3	--	--	--	--
	Down	--	--	--	--	--	--	--	--	--	--	--	--	--	1.7
Iron and steel	Up	2.5	3.2	3.1	2.4	1.8	2.0	2.3	1.5	2.0	1.3	1.3	1.6	2.1	1.6
	Down	2.7	3.1	1.7	2.3	1.7	1.8	1.8	4.2	2.9	2.5	1.8	1.9	2.4	2.1
Industrial and agricultural chemicals	Up	10.4	8.2	7.7	8.0	7.2	6.9	8.2	9.7	8.4	9.5	8.8	9.2	8.5	11.7
	Down	--	--	--	--	--	--	--	1.3	1.3	1.4	1.3	1.3	--	1.0
Other	Up	6.5	7.4	7.0	6.0	8.8	8.8	4.8	7.0	8.5	11.3	9.2	9.2	7.9	5.4
	Down	1.6	2.0	1.5	1.4	1.3	2.3	--	1.1	1.6	2.2	3.0	1.5	1.6	2.7
Total tonnage	Up	971.0	1346.0	1804.0	1928.0	2367.0	2257.0	1774.0	1817.0	2233.0	2489.0	1792.0	1595.0	2237.3	2442.0
	Down	1926.0	3022.0	2854.0	3188.0	3675.0	3713.0	3088.0	2677.0	2399.0	2876.0	2975.0	2336.0	3472.9	2539.0
Total percentage	Up	33.5	30.8	38.7	37.7	39.2	37.8	36.5	40.4	48.2	46.4	37.6	40.6	39.0	49.0
	Down	66.5	69.2	61.3	62.3	60.8	62.2	63.5	59.6	51.8	53.6	62.4	59.4	61.0	51.0

Note: A dash (--) indicates percentage was less than 1.0.
Source of data: PMS and Lockmaster data.

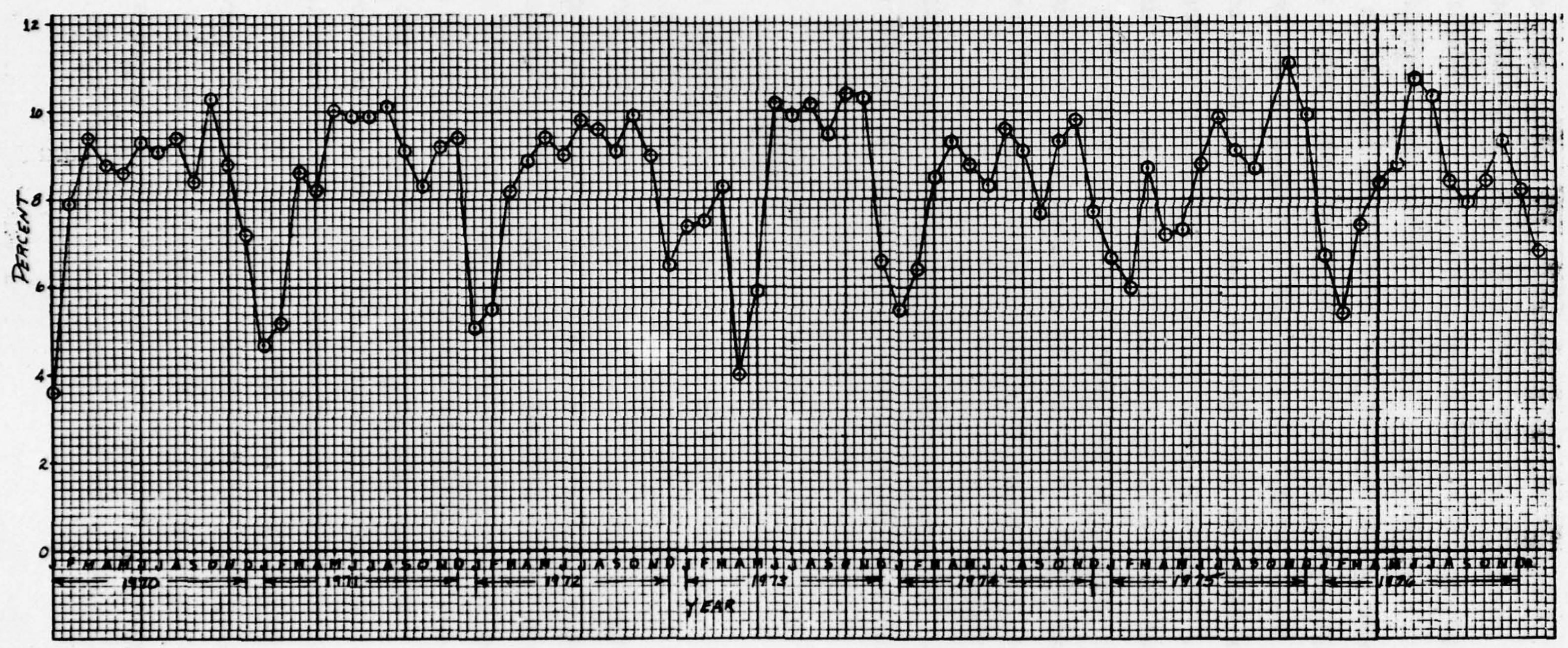


Figure 8. Monthly distribution of commodity movements, L&D 26, years 1970-1976

freezes. Another dip in the percent of annual tonnage locked can be observed in April and May 1973 when major flooding on the upper Mississippi and Missouri Rivers occurred. Considering April through November to be the major shipping period for determining lock capacity, the average percentage of the commodities carried in any month was 9.22 for a multiplying factor of 10.85 (Table 5). The 9.22 percent compares with the value of 8.7 percent and 10.5 used in the DM11 study. This value was based on the observed peak traffic month to that date.

49. Figure 9 shows the wide variability of grain movements throughout the year, particularly during the last three years. The impact of these peak movements has not been directly taken into account in this analysis. However, it is clear that such peaks will cause serious delays and traffic backups for periods of time during the "average" year.

50. The annual commodity movements through L&D 26, L&D 25, and L&D 27 during 1976 are shown in Tables 6, 7, and 8, respectively.

Fleet Characteristics

51. One of the key issues in the controversy concerning the capacity of L&D 26 involves the fleet characteristics of the tows passing these locks. Some of the capacities that have been cited in non-Corps of Engineers statements and publications appear to have been based upon tow configurations of only 15 Jumbo barges (35 × 195 ft). This type of tow configuration is such that it will require a double lockage and will fill the chamber in both cuts with an allowance for the towboat. However, not all tows consist of all Jumbo barges and not all tows are, and probably never will be, the maximum tow size. Many tows involve integrated barges which are generally much larger in size, ranging from 200 to over 300 ft long and 52 to 54 ft wide. Naturally, a tow consisting of such large barges can be of approximately the same overall length and width but contain a much smaller number of barges. For example, an 8-barge tow of 52- × 260-ft barges will be equivalent to a 15-barge tow of the Jumbo size. Therefore, it is easily observed

Table 5

Monthly Distribution of Commodity Movements, Lock and Dam 26

Percent of Annual Tonnage

Month	1970	1971	1972	1973	1974	1975	1976	Avg
Jan	3.8	4.7	5.1	7.4	5.5	6.7	5.4	5.5
Feb	6.9	5.2	5.5	7.5	6.4	6.0	7.4	6.4
Mar	9.4	8.6	8.2	8.3	8.5	8.7	8.4	8.6
Apr	8.8	8.2	8.9	4.0	9.3	7.2	8.8	7.9
May	8.6	10.0	9.4	5.9	8.8	7.3	10.7	8.7
Jun	9.3	9.9	9.0	10.2	8.3	8.8	10.3	9.4
Jul	9.1	9.9	9.8	9.9	9.6	9.8	8.4	9.5
Aug	9.4	10.1	9.6	10.2	9.1	9.1	7.9	9.3
Sep	8.4	9.1	9.1	9.5	7.7	8.7	8.4	8.7
Oct	10.3	8.3	9.9	10.4	9.3	11.1	9.3	9.8
Nov	8.8	8.6	9.0	10.3	9.8	9.9	8.2	9.2
Dec	7.2	7.4	6.5	6.6	7.7	6.7	6.8	7.0
Total Tonnage	48,673	46,227	54,041	51,336	52,949	54,569	57,875	

Source of data: Lockmaster records.

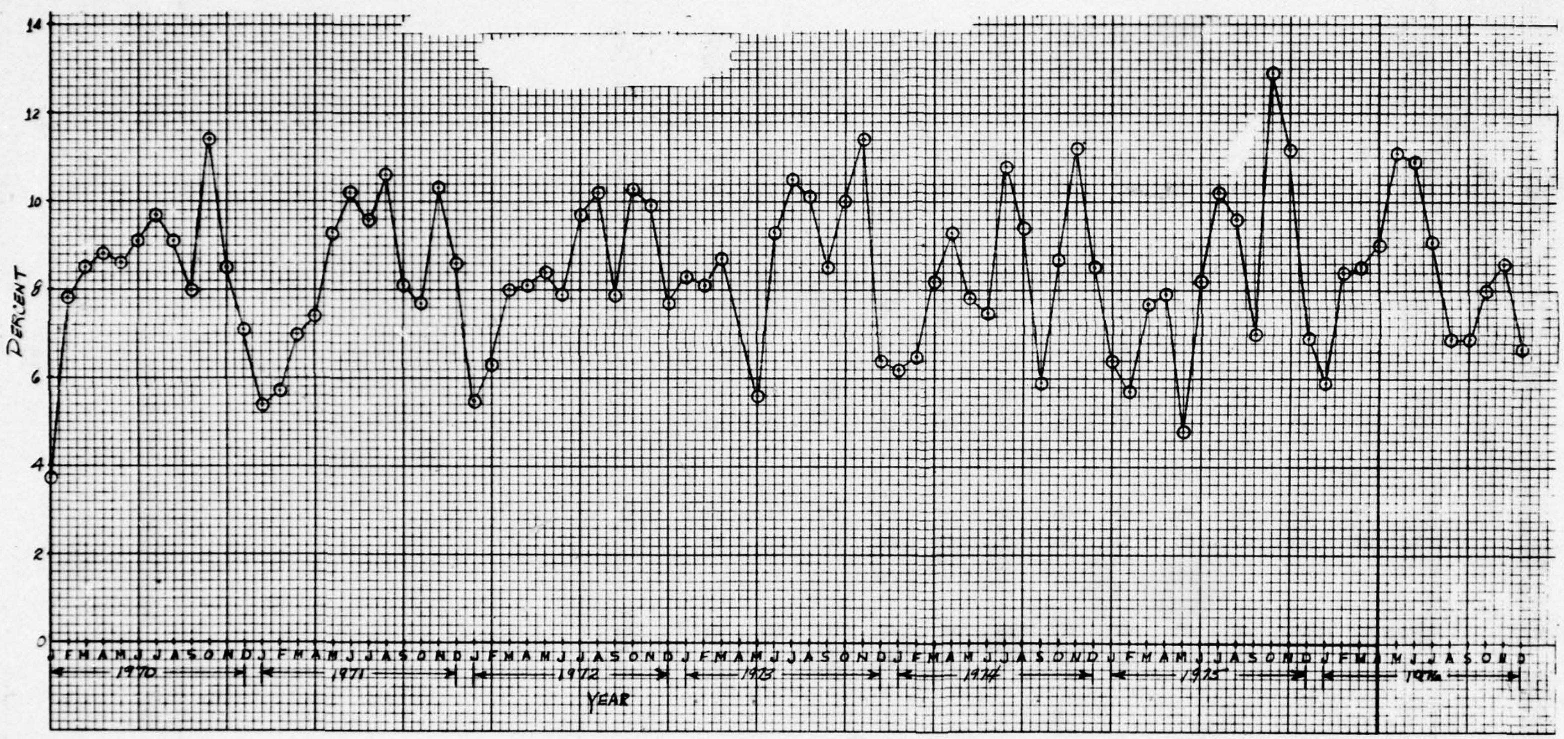


Figure 9. Monthly distribution of grain movements, L&D 26, years 1970-1976

Table 6

Commodity Movements Through L&D 26 During the Year 1976

Commodity	Up	Down	Total
Corn	34,622	20,866,934	20,901,556
Soybeans	9,989	4,833,685	4,834,674
Other grains	5,263,174	2,974,637	3,037,811
Coal	5,279,190	66,097	5,345,287
Petroleum and petroleum products	5,513,870	1,729,148	7,243,018
Cement, sand, stone, aggregate	269,818	373,558	643,376
Iron and steel	1,340,052	1,308,350	2,648,402
Industrial chemicals	4,739,539	287,038	5,036,577
Agricultural chemicals	3,119,922	50,500	3,170,422
Other and miscellaneous	1,100,934	2,973,669	4,074,603
Total	21,471,110	35,463,616	56,934,726

Source: Preliminary Waterborne Commerce Statistics Center Data.

Table 7

Commodity Movements Through L&D 25 During the Year 1976

Commodity	Up	Down	Total
Grain	125,700	14,063,450	14,189,150
Coal	3,718,100	100,200	3,818,300
Petroleum and petroleum products	2,292,502	205,662	2,498,164
Cement, sand, stone, aggregate	169,000	821,250	990,250
Iron and steel	197,050	75,600	272,650
Chemicals	1,316,732	133,850	1,450,582
Miscellaneous	1,631,665	213,100	1,844,765
Total	9,450,749	15,613,112	25,063,861

Source: *Preliminary* Waterborne Commerce Statistics Center Data.

Table 8

Commodity Movements Through L&D 27 During the Year 1976

Commodity	Up	Down	Total
Grain	427,635	32,544,235	32,971,870
Coal	5,243,750	295,300	5,539,050
Petroleum and petroleum products	5,271,243	5,063,598	10,334,841
Cement, sand, stone, aggregate	245,050	339,300	584,350
Iron and steel	1,232,192	1,326,084	2,558,276
Chemicals	5,382,022	745,443	6,127,465
Miscellaneous	5,072,174	1,336,136	6,408,310
Total	22,874,066	41,650,096	64,524,162

Source: Preliminary Waterborne Commerce Statistics Center Data.

that one cannot generalize the size distribution of tows in terms of barges alone.

52. Keeping this in mind, the trends in tow sizes can now be investigated. The historical growth in tow sizes, considering barges per tow and tons per tow, is presented in Figure 10. Tons/tow and barges/tow are derived by dividing the tonnage and number of barges by the total towboats passed during the year. The total towboats include those towboats locked that were pushing no barges, i.e., lightboats. This was necessary to obtain the long history since in earlier years the number of lightboats was not recorded separately from the commercial tows. Using a linear regression analysis, the long-term growth has been determined to be 1.3 barges/tow, 102 tons/barge, and 1505 tons/tow over each decade for the past 30 years. This increase in all of these factors indicates that there has been some increase in loads carried and in the overall size of tows over this period of time. The increase in the tonnage carried by each barge and tow could have been influenced by decreased empty movements or increased drafts, as well as increased barge dimensions. The increase in barges per tow could be due to a change to smaller barges and fewer integrated barges. However, it is known that over the long-term growth, tows have increased in overall dimensions.

53. One of the reasons for larger tows is the corresponding increase in the horsepower of the towboats used on the upper Mississippi and Illinois Waterway. Figure 11 shows that there has been a parallel growth of towboat horsepower and barges being pushed by a tow. The average horsepower was determined from lockmaster records for selected months. The impact of towboat power to tow size is further demonstrated in a review of tow size and towboat horsepower during the month of March 1976 (Figure 12). The trend is a steady increase in horsepower being used to push the larger tows, although a wide spread of towboat horsepower is observed for any tow size. The grouping of tow sizes in the 2-, 3-, 6-, 9-, 12-, and 15-barge groups can also be observed. Typically, the 2-, 3-, and 6-barge tows will consist of petroleum or chemical integrated barges.

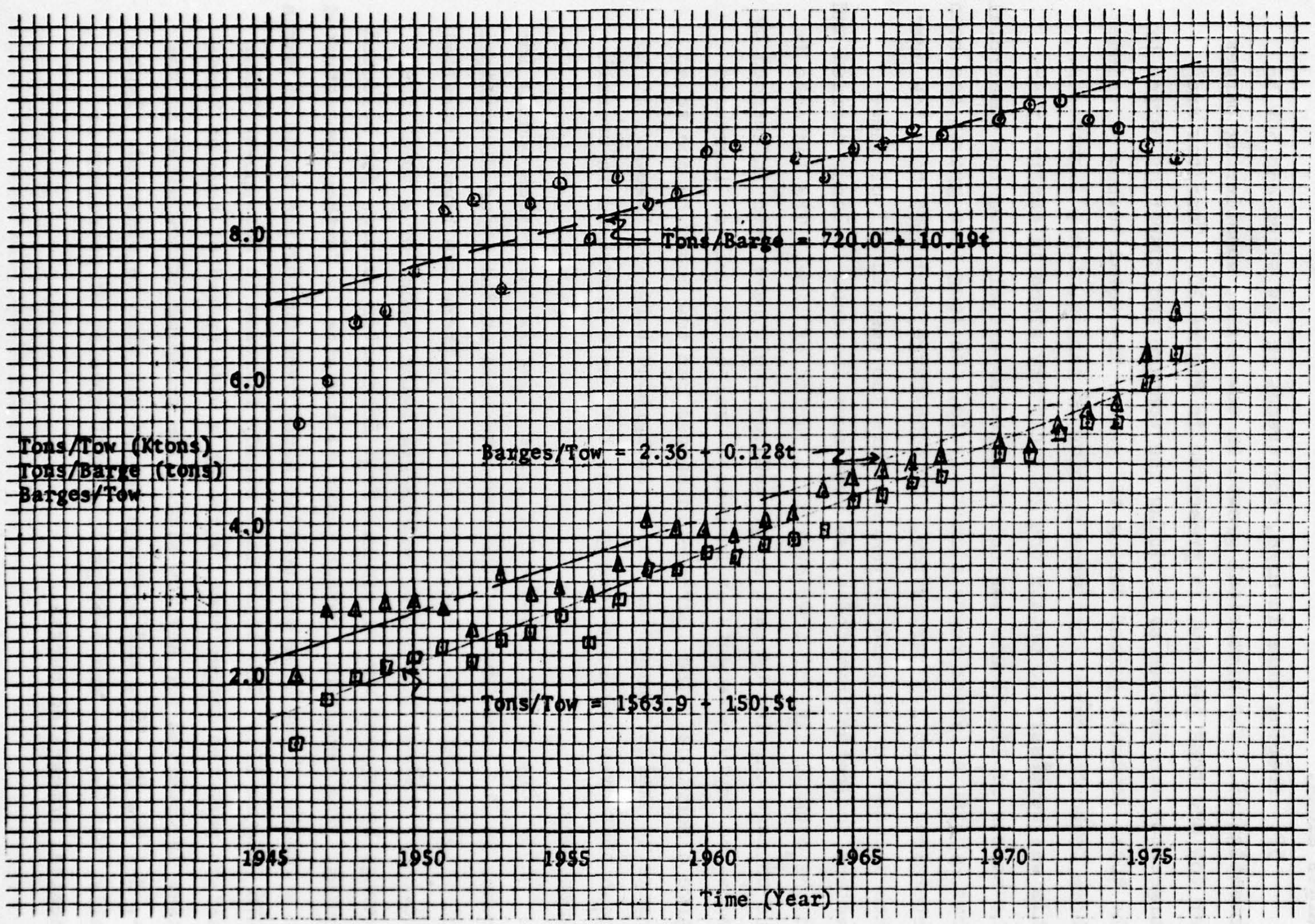


Figure 10. Historical trends in tow size, L&D 26

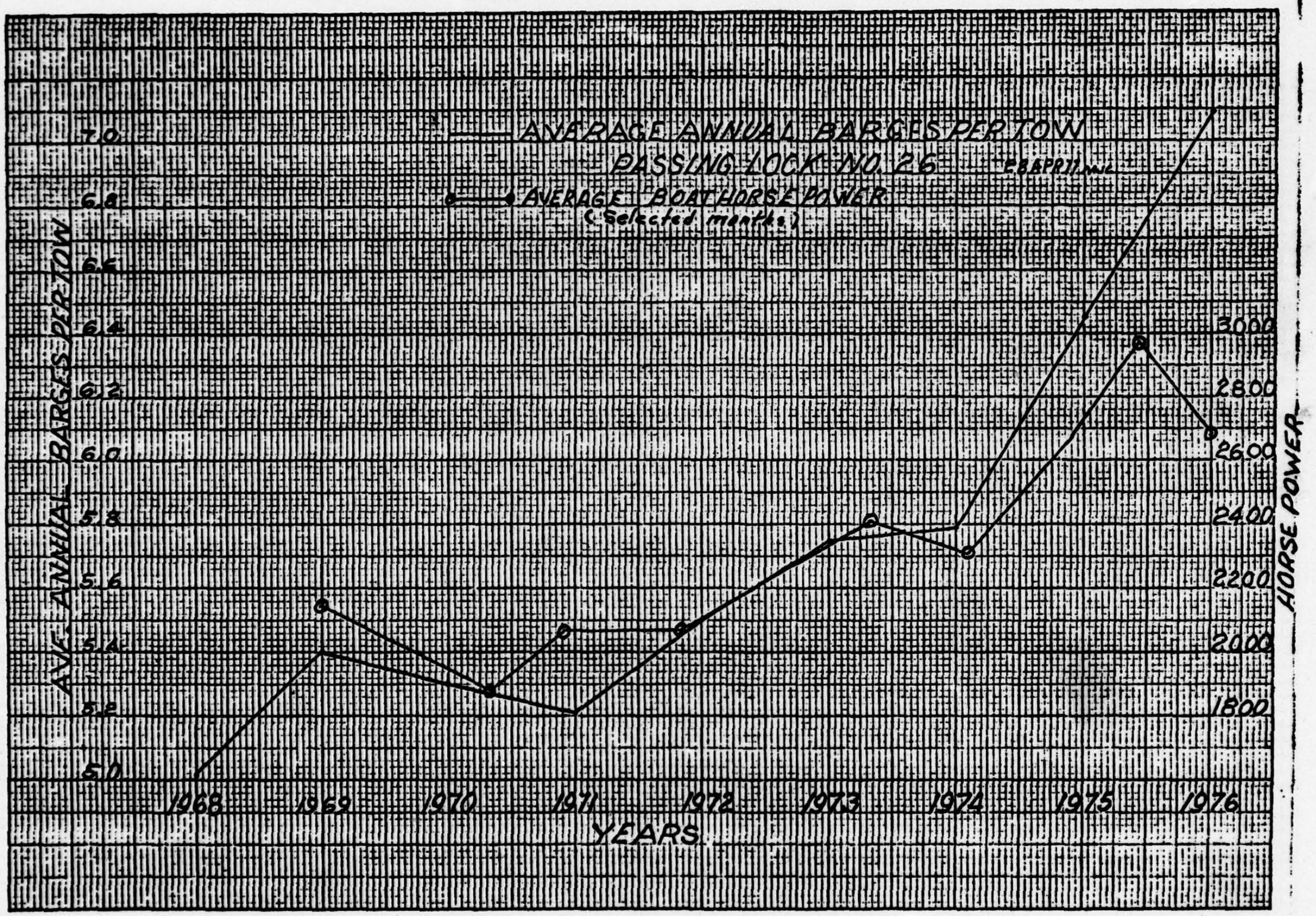


Figure 11. Comparison of towboat horsepower and barges

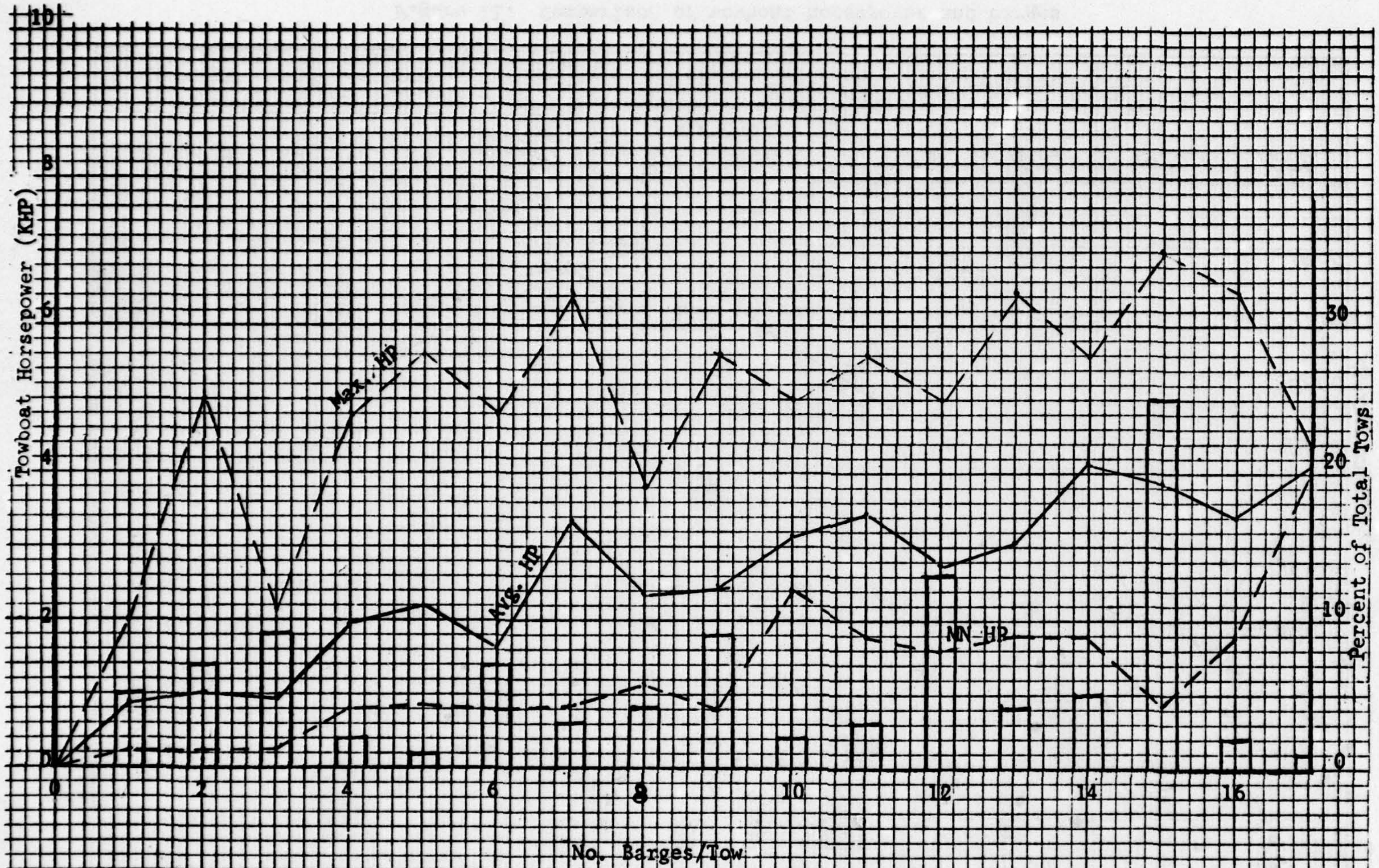


Figure 12. Tow size-horsepower relation, L&D 26, March 1976 PMS data

54. An analysis of more recent data, with the influence of lightboats removed, yields additional insight into recent trends in tow characteristics. Figure 13 indicates that over the past 6 years tows have increased from an average of about 6 barges per tow to over 8.0 barges per tow. During this time, however there was a decrease in the average load per barge from 990 tons to just under 920 tons. Both of these changes could be due to a significant increase in the number of grain movements, a corresponding increase in the number of Jumbo barges being used relative to integrated barges and an increase in the number of empty movements required to balance the increased grain movements. Overall there was an increase in the loads carried by the average tow of nearly 1400 tons, approximately one Jumbo barge load. This is a very rapid increase over a short period of time and reflects the increased size of the grain movements to New Orleans for overseas export in recent years. With increased shipment sizes, larger groups of barges can be made available for tows, similar to the massive movements required for unit train movements.

55. Analysis of the average tow size for various horsepower towboat classes reveals that although the average tow size and power of towboats has steadily increased over the years, a significant number of small towboats are still operating that push small tows, in terms of barges/tow. For example, as shown in Figure 14, the largest percentage of towboat horsepower pushing tows other than petroleum tows are in the horsepower range from 600 to 1600 horsepower and are pushing an average of 4- to 5-barge tows. These tows are typically single lockage tows in the 600-ft chamber at L&D 26. The next major group is the 2800 to 3800 horsepower group that is pushing 11- to 12-barge tows. A large percentage of petroleum tows are in the 600 to 2100 and the 2800 to 3800 horsepower classes which push 2- to 4- and 4- to 5-barge tows, respectively, as shown in Figure 15. Depending on the size of the barge, a 4-barge petroleum tow may be a single or a double lockage in the 600-ft chamber at L&D 26. Because of the capital investment in these towboats and considering that these average tow sizes indicate safe

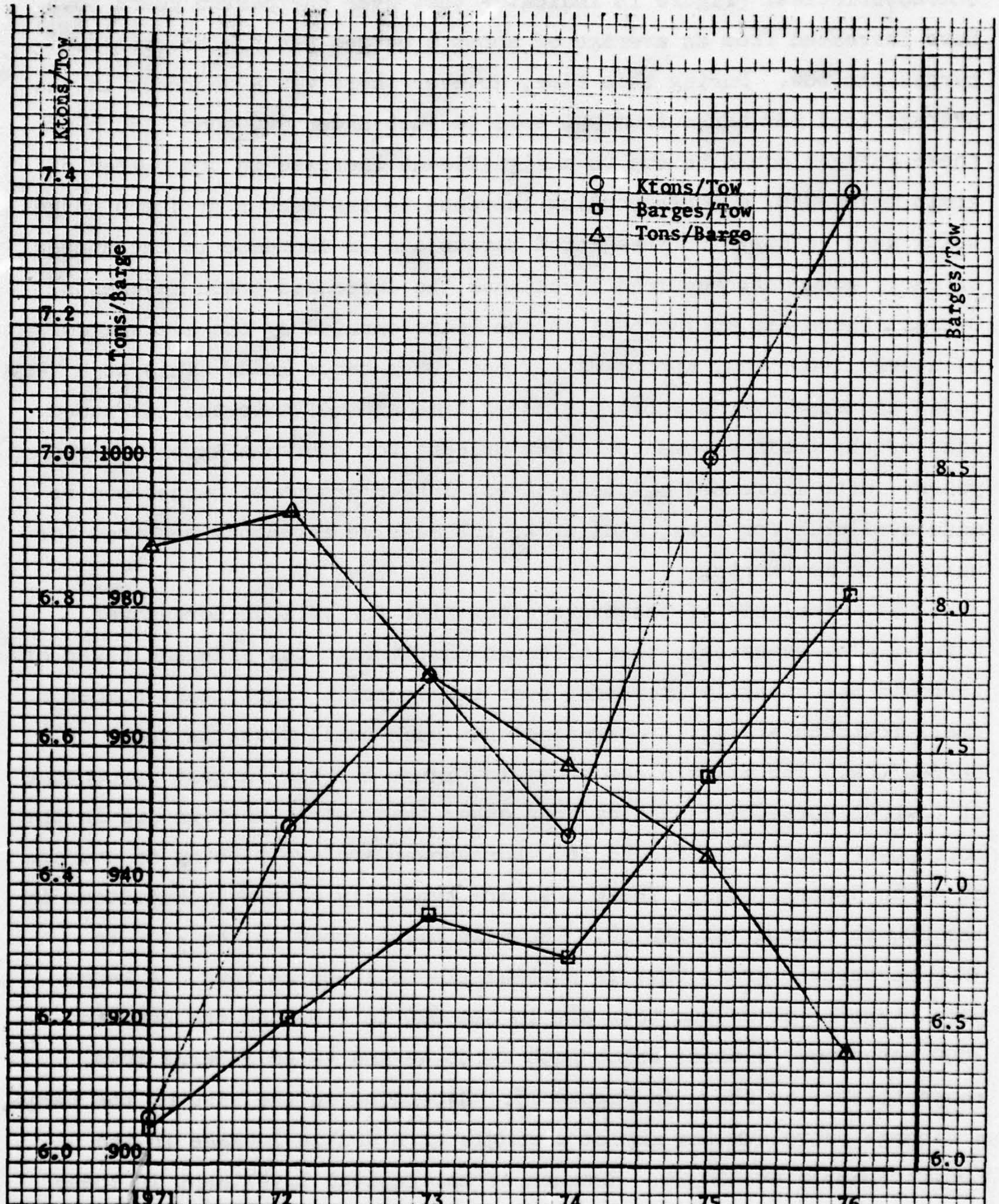


Figure 13. Tow/barge/tonnage relations L&D 26

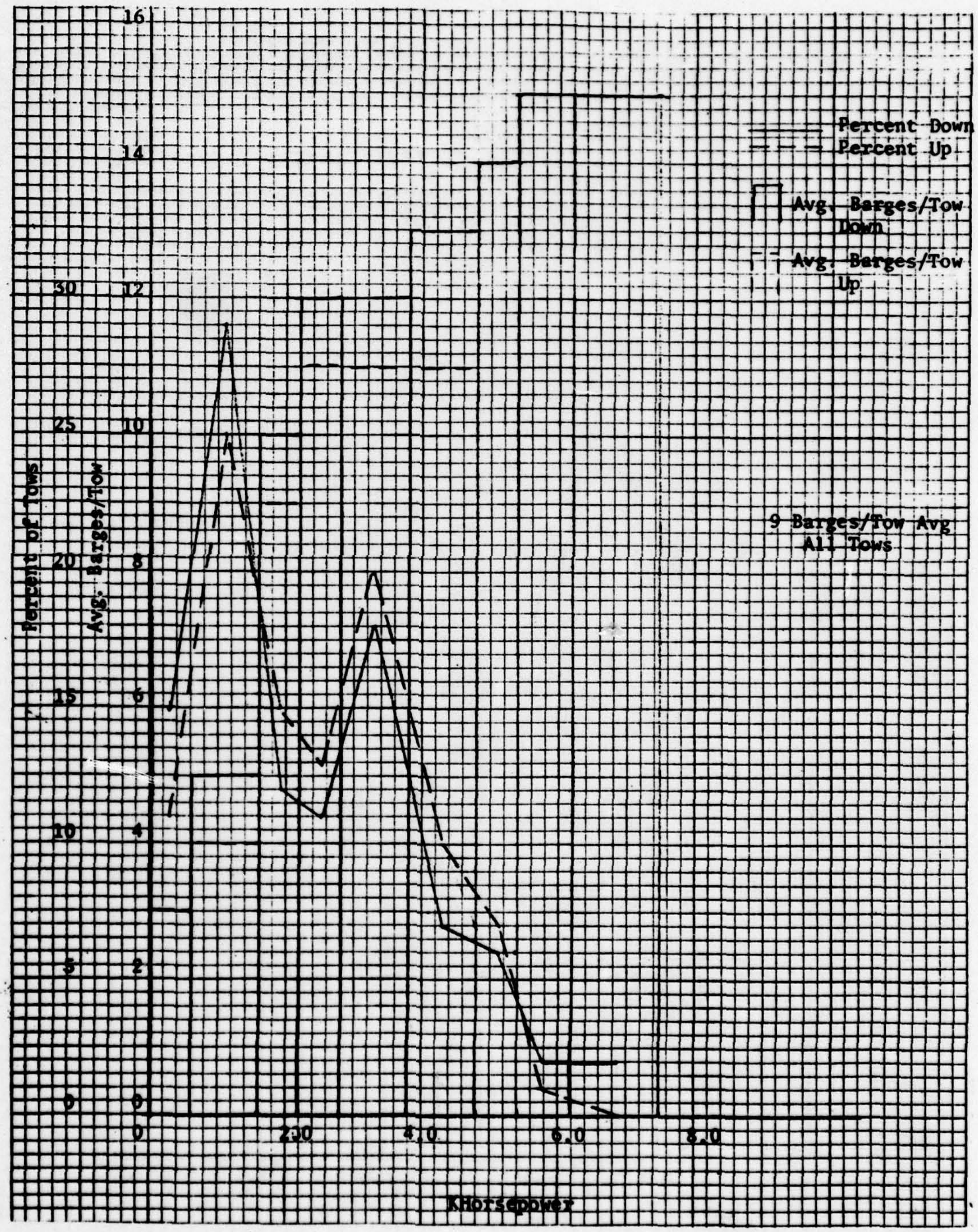


Figure 14. Tow size/towboat horsepower relation--all tows not petro L&D 26--Aug 75 PMS

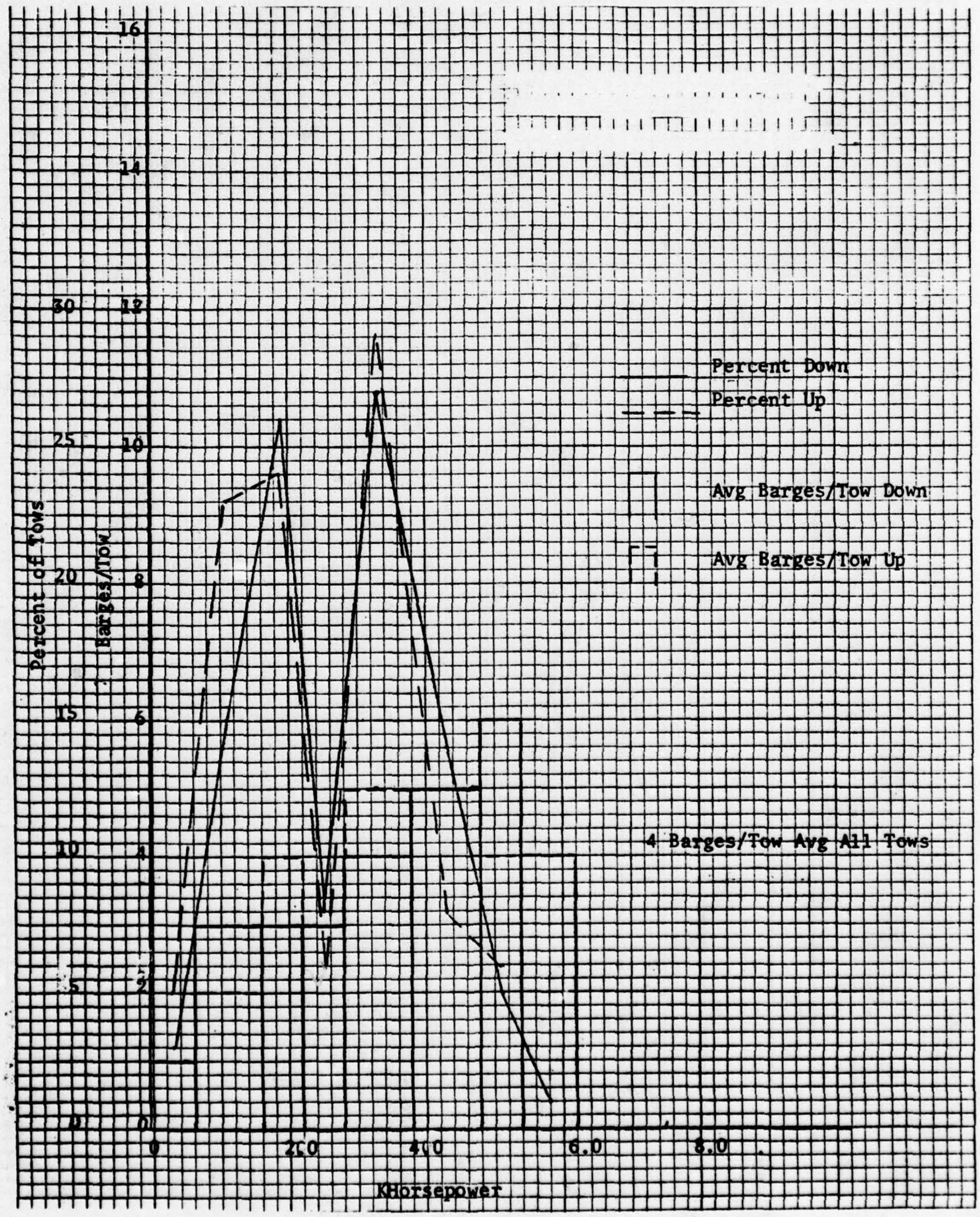


Figure 15. Tow size/towboat horsepower relation--
petro. tows L&D 26--Aug 75 PMS

operating limits, the small tows will undoubtedly remain in the operating fleet for some time to come.

56. The only way a constant tow size of lock filling dimensions can be considered to be present for all lockages is to require all tows to be refleeted prior to approaching the lock and upon exiting the lock. This type of operation would require a major refleeting area in pools that are on either side of the lock and would involve difficult operational, insurance, and legal problems. Managing such an operation would be a major undertaking.

57. One final observation concerning tow characteristics can be obtained from monthly values of unit parameters. Figure 16 shows that there is a significant month-to-month variation in tow characteristics throughout the two years indicated. This variation is even more pronounced when the traffic through the chambers is analyzed separately (Figures 17 and 18). One observes that the average barges per tow vary from 8.2 to 12 in the main chamber and from 2.1 and 4.6 in the auxiliary chamber. The percentage of empty barges varies from 27 to 44 in the main chamber and from 37 to 57 in the auxiliary chamber. The small tow sizes, the large tons/barge, and the high percentage of empty barges indicate that a relatively high percentage of petroleum and chemical barges use the auxiliary chamber. This usage increases dramatically with increases in tows using the locks, i.e., the auxiliary chamber tends to absorb the extra loading imposed on L&D 26.

Lockage Times

58. The third major element in determining a lock's capacity to process vessels is the service time required to pass tows from one side of the lock to the opposite side. As noted above, this service time is a function of the chamber size, the type of lockage required to process the tow being served, the type of approach and exit used, and the direction in which locking operation takes place. In the DM11 analysis the lockage component times were based upon data collected by Peat, Marwick, Mitchell and Company during tests that were in progress when the

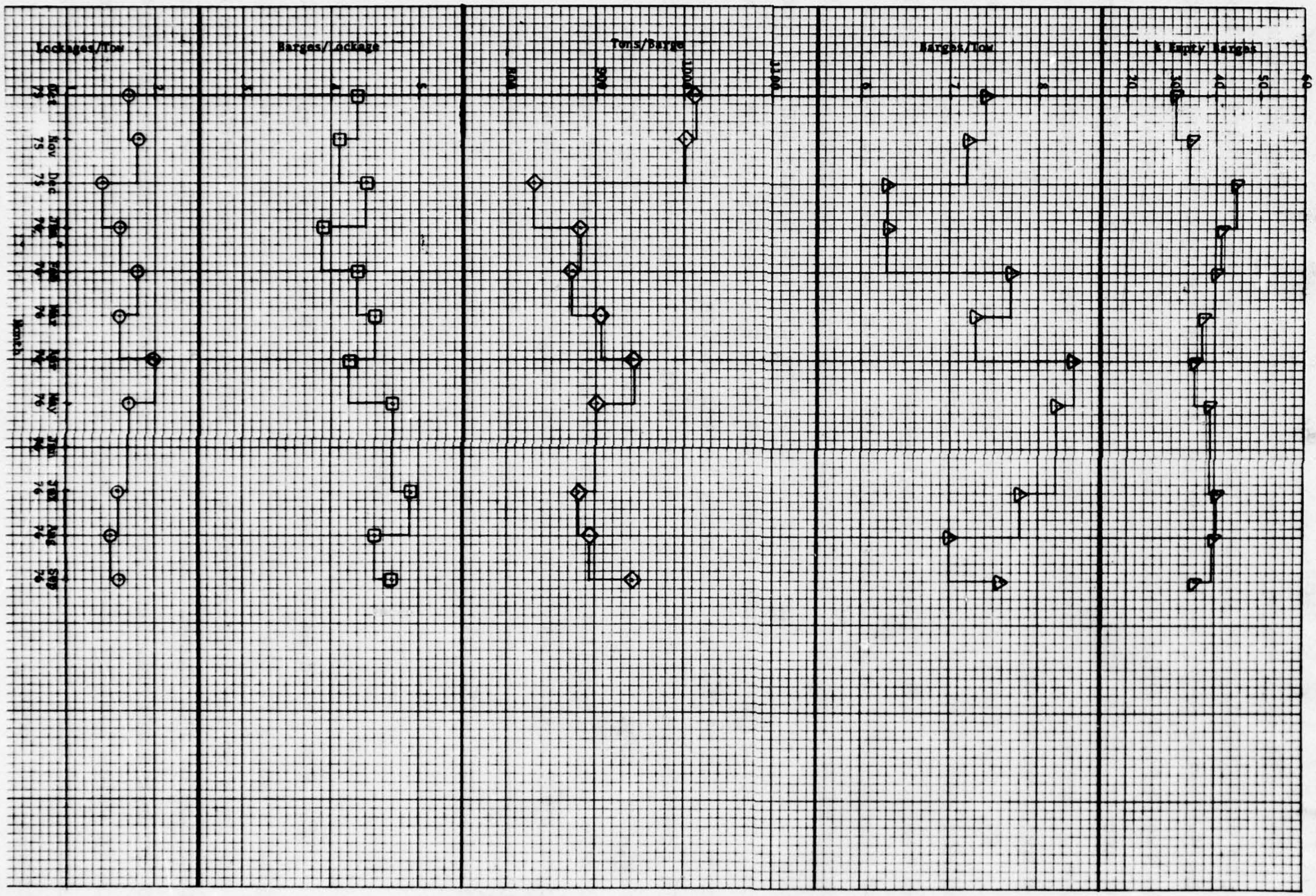


Figure 16. Lock/traffic relations--variations L&D 26--both chambers

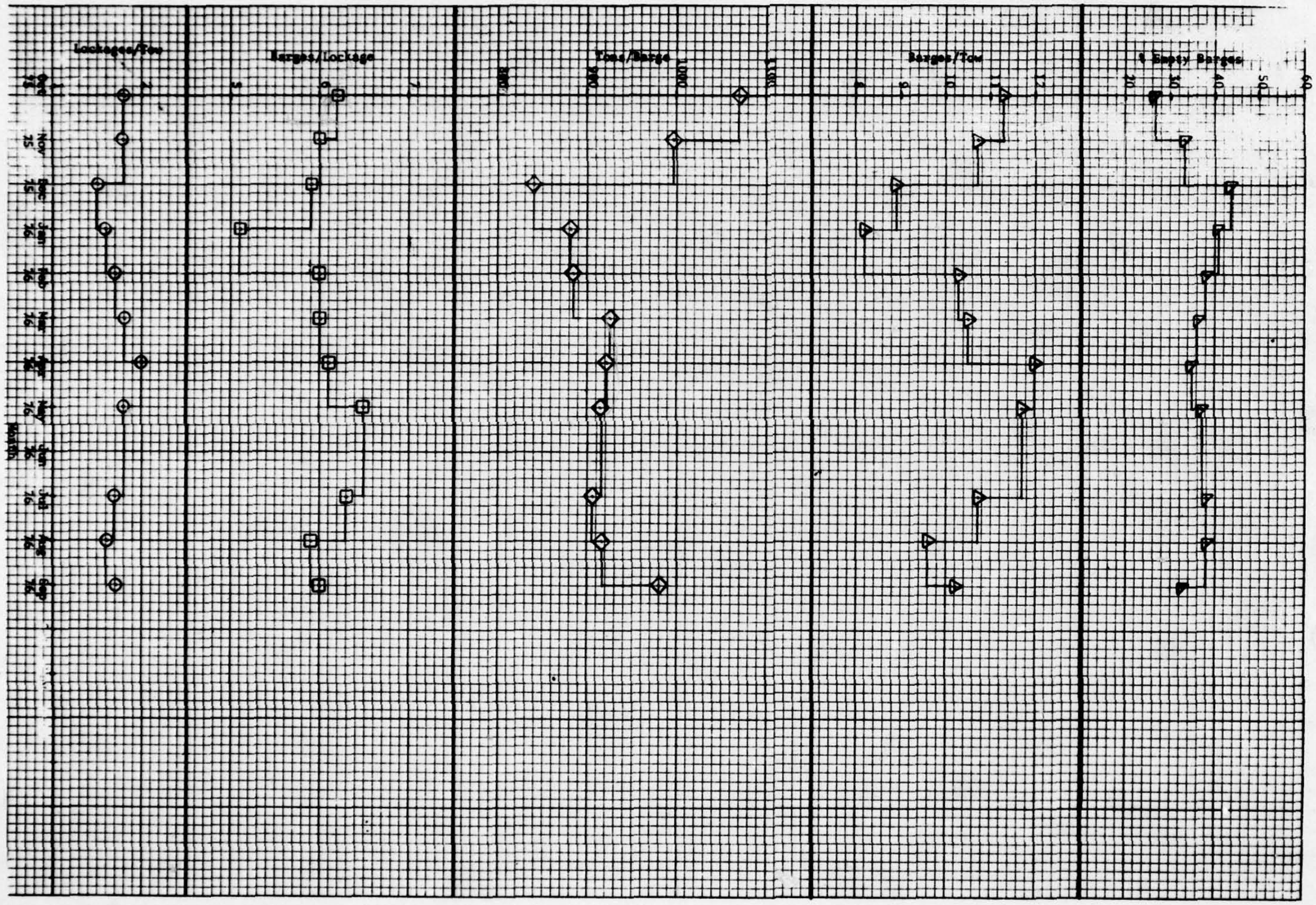


Figure 17. Lock/traffic relations--variations L&D 26 main chamber

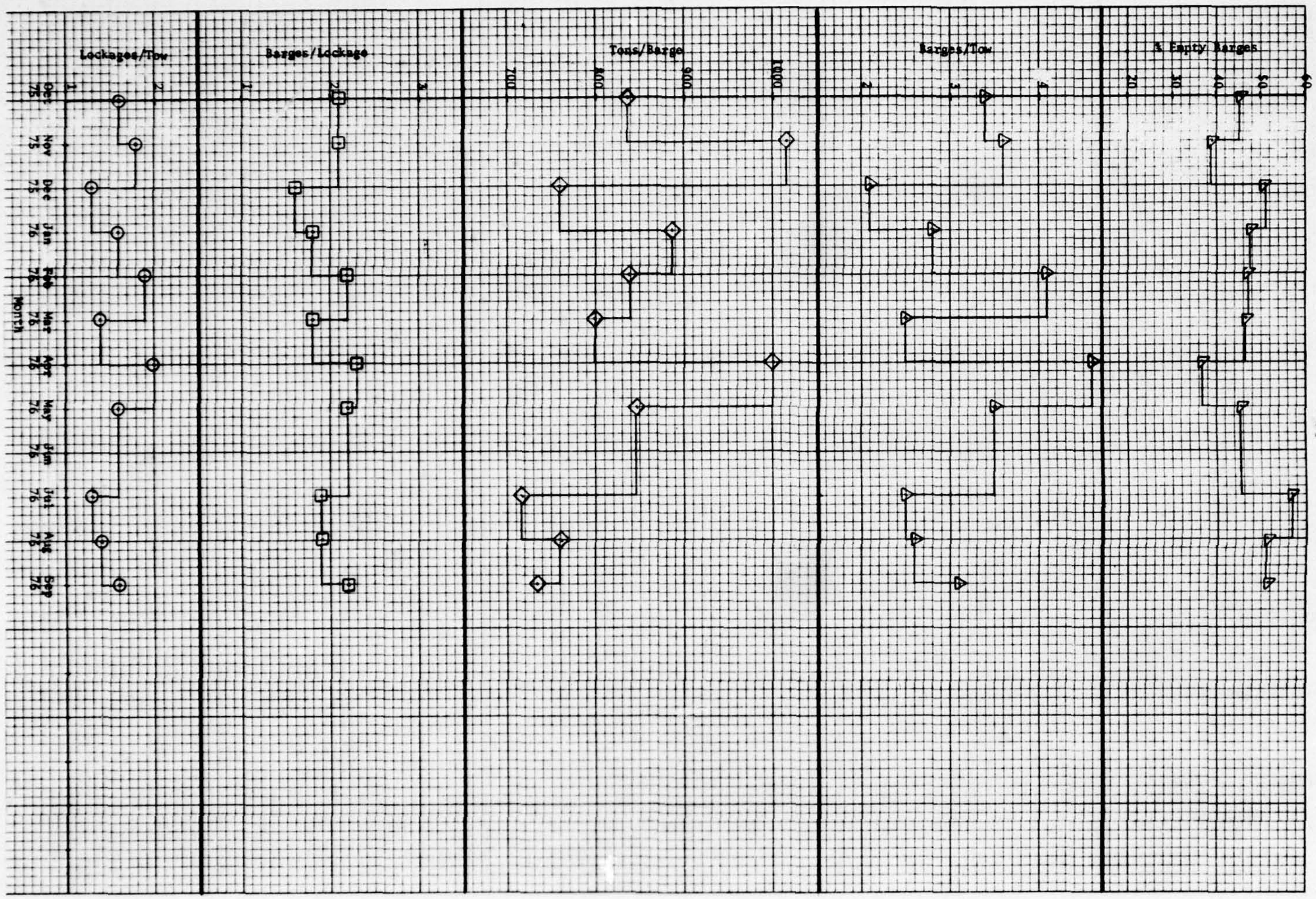


Figure 18. Lock/traffic relations--variations L&D 26 auxiliary chamber

capacity was being determined for the DM11. A discussion of these results is contained in Appendix B.

59. For the reanalysis of LD26, the determination of more recent locking times was based on PMS data. Figures 19 and 20 present the average locking times from each lockage type and for all lockages in the main and auxiliary chambers. One can observe a wide variance in the average monthly processing times. The times include the entire time from the beginning of the lockage of a vessel to the end of lockage of the last cut of the vessel, if more than one cut was required. The primary influence of the double lockages over all other lockage types on the overall average processing time in the main chamber is readily apparent from the parallel nature of the two curves. Double lockages consistently are over 75 percent of the main chamber lockages as shown in Figure 21.

60. One notices a significant reduction in processing times for doubles in the main chamber beginning in April. An accident in late March caused enforced restrictions to tow operations during April 1976, including limited tow sizes and the required use of helper boats in approaches and exits. Due to an extremely long backlog of tows waiting at the locks following this period, a locking procedure was used in which switchboats assisted in removing tows from the locks so that they could clear the lock gates while refleeting (IC procedure). This procedure was used during May and carried over into the summer months, although it was not enforced, and significantly reduced the locking times required for double lockages. Beginning in mid-October 1976, the IC operating policy was made the normal operating policy for L&D 26. November 1976 was the first full month of locking under this policy with "normal" conditions; thus this month was used as the basis of capacity calculations for the IC policy.

61. The average processing time of the auxiliary lock is not as dominated by the double lockage times as it is in the main chamber. Figure 22 shows that double lockages are not the overwhelming majority of the lockage types. The auxiliary chamber is, however, heavily influenced by the occurrences of multivessel lockages. As the main

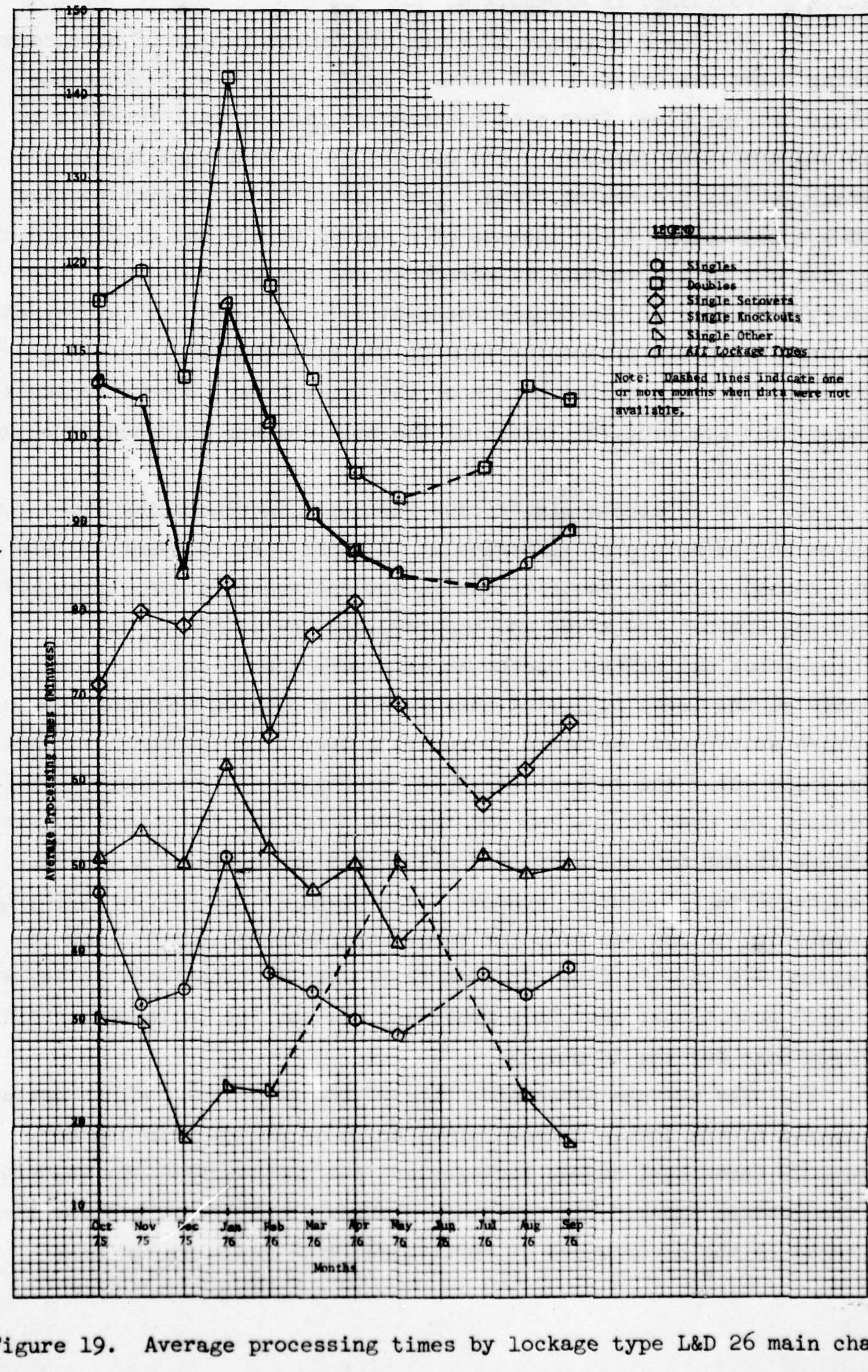


Figure 19. Average processing times by lockage type L&D 26 main chamber

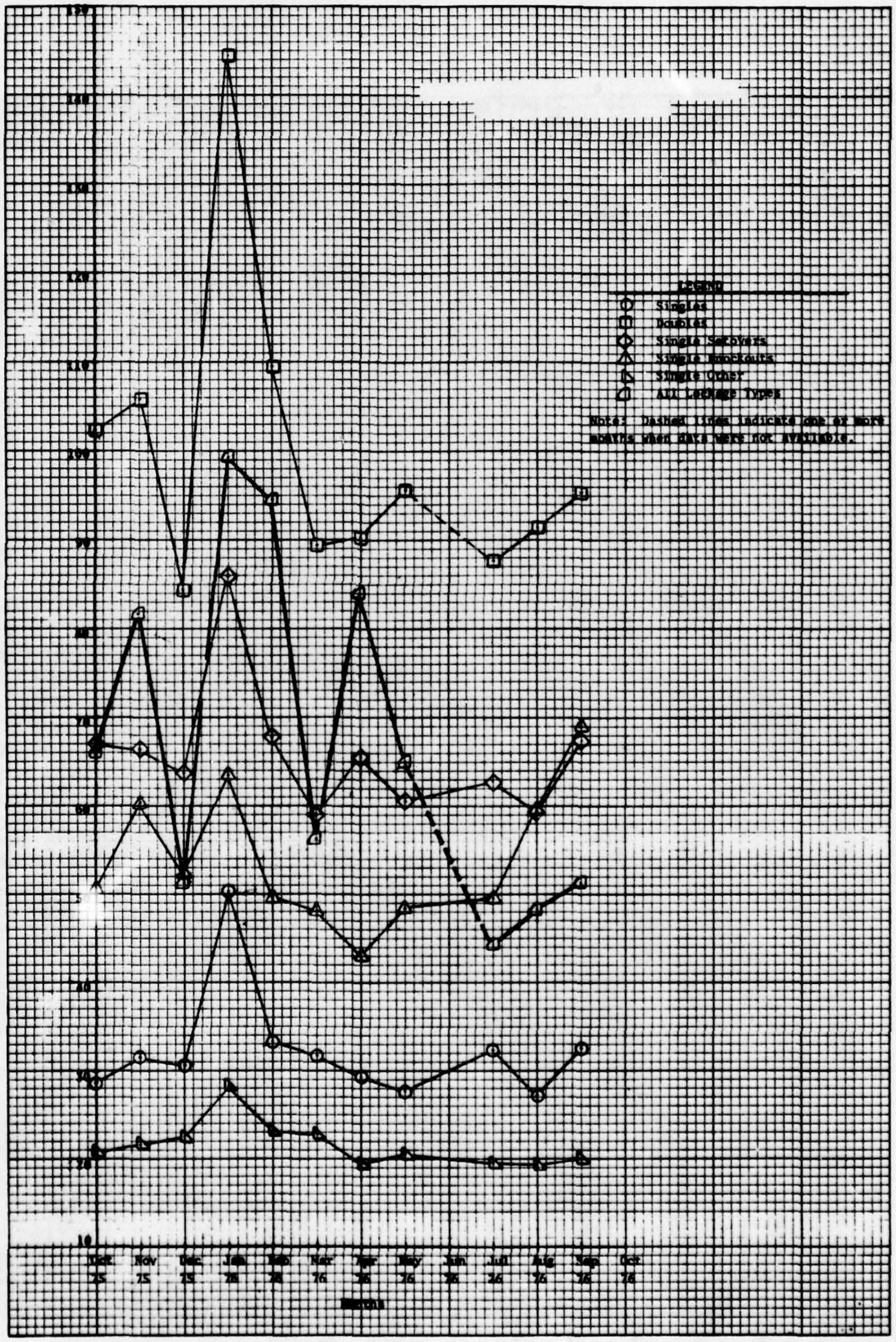


Figure 20. Average processing times by lockage type L&D 26 auxiliary chamber

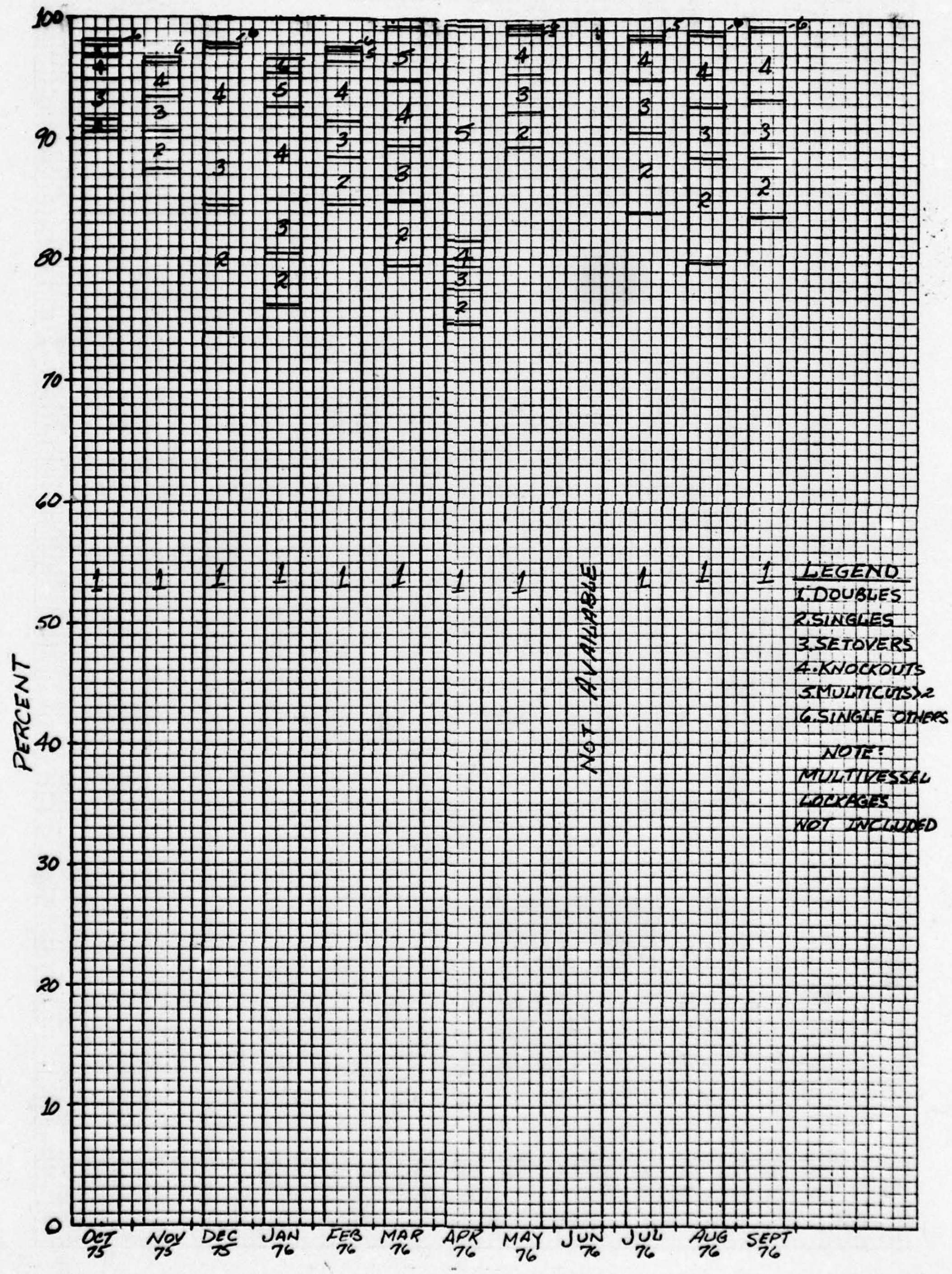


Figure 21. L&D 26 main chamber lockage type distributions

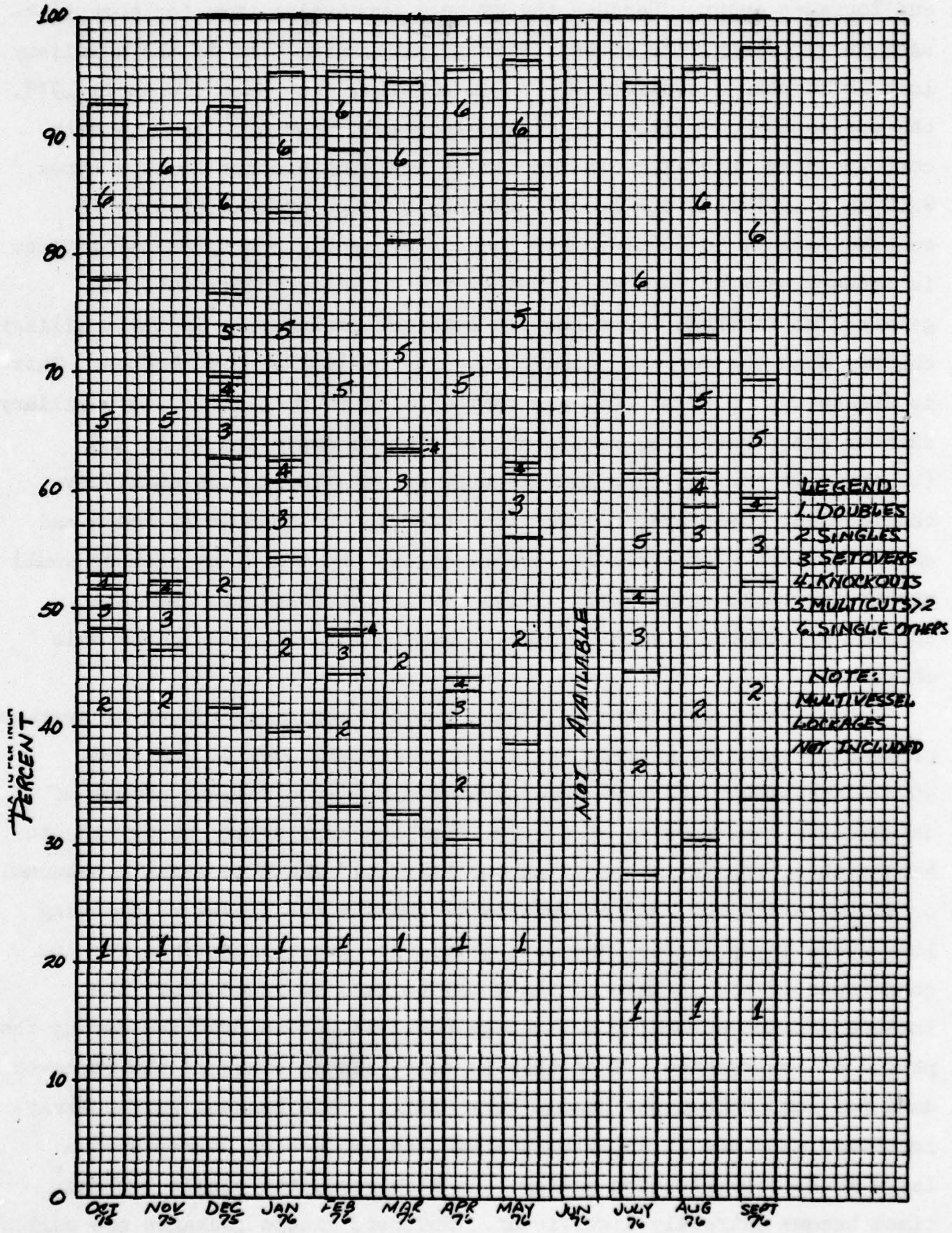


Figure 22. L&D 26 auxiliary chamber lockage type distributions

chamber is more heavily utilized and the traffic that normally would prefer the main chamber begins to use the auxiliary chamber, more multicut lockages occur. Because the average processing time for such lockages is very long, the overall average processing time in the auxiliary lock is increased considerably. For example, from March to April 1976, the percentage of multicut lockages increased from 17.8 to 44.4 with corresponding reductions in the single and single other lockage types. With this increase, the overall monthly average processing time increased from 56 to 84 min. All lockage types had peak processing times in January; again, this was probably due to icing conditions. In general, all lockage types require less processing time in the auxiliary chamber than the corresponding lockage types in the main chamber. This is due to two factors: (a) the chamber size is smaller in the auxiliary chamber and, therefore, requires less time to empty and fill, and (b) the tows for the same lockage type are smaller in the auxiliary chamber and, therefore, require less time in the chamber approach and exit maneuvers. As a result, processing in the auxiliary chamber would appear favorable to the main chamber until one considers that the tonnage processed in each lockage is generally less than in the main chamber.

62. The fact that all lockage types experienced ranges of average processing times of at least 20 min and some are over 30 and even 40 min throughout the year demonstrates the very difficult nature of determining the capacity of a lock. Various approaches can be made to handle this, including selecting the "typical" month or using a seasonal or annual average. When one wishes to analyze the impact of changing lock operating policies, one must obtain the processing times for the components of the lockage so these may be used to reconstruct the lockage process according to lockage policies not in practice during the period of observation. When this is done, sample sizes of the observed data for some components become very small. This becomes particularly important when one is applying the RTS tow processing policy with a large NU-ND tow selection policy. In this case, the single lockage times become extremely significant. However, single lockages are only a

small part of the total lockage pattern and become especially small when the approach and exit times are separated by direction and type (fly, exchange, and turnback). Thus, while both approaches were used in this analysis of lock capacities for L&D 26, the method using weighted seasonal average processing times is considered to be the most meaningful.

63. In the discussion of the method for computing the lock capacity, there was a discussion of the significance of lock setup time; i.e., the time it takes to clear the lock after the last cut of a lockage is completed and the gates of the lock chamber have been opened to discharge the locked vessel until the lock has been prepared for the next vessel to be locked and that vessel has approached the lock and the bow of that vessel has entered into the chamber. Significant times in this setup time are the approach and the exit lockage components. Two types of approaches and exits are significant in determining lock capacities--exchange and turnback.

64. An exchange approach and exit occur when the exiting and the entering vessels are traveling in opposite directions and they exchange the use of the lock at the approach point or somewhere in the approach channel, if possible. In this case, the exit begins as soon as the lock gates are fully in their recesses and ends when the bow of the exiting tow has passed the stern of the entering tow or the approach point, whichever is first. The exchange approach begins when the exit of the exiting tow ends and ends when the entering tow's bow crosses the sill at the open gates.

65. A turnback approach and exit occur when the exiting and entering tows are traveling in the same direction. In this case the lock must be reversed between the exit and approach to serve the follow-on tow. The turnback exit begins as soon as the gates have opened and are fully in their recesses and ends when the tow has cleared the lock sufficiently so that the gates may be closed. The turnback approach will begin as soon as the lock has been reversed and the gates have been opened and are fully in their recesses, and ends when the tow's bow has crossed the sill at the open gates.

66. When a turnback approach is required the entering tow will approach the lock through the approach channel and tie to the approach wall near the lock gate, awaiting the lock's reversal. Thus, the turnback approach will normally be much shorter than the exchange approach. Likewise the turnback exit will end before the exiting tow has transited the exit approach and, therefore, will be much shorter than the exchange exit. If the sum of the average turnback approach and exit and the intervening lock reversal (turnback) times are less than the sum of the average exchange approach and exit, there is a time-saving advantage in using consecutive lockages in a single direction. However, one must recognize that forced delays will result when tows are selected for lockage in some manner other than the arrival order.

67. A third type of approach and exit does exist. However, this type of approach and exit occurs only when there is no vessel waiting to be serviced at the lock; therefore it is of no significance in determining a lock's capacity.

68. In all exit types during the standard lock operating policy followed at most locks, multicut lockages will recouple on the lock wall before exiting the lock chamber. Thus, the lock cannot be used during this procedure and the time required to recouple is included in the exit times recorded. Other lock operating policies do not allow this and make provisions for extracting the unpowered cut and re-forming the tow at some point clear of the lock chamber. The IC processing procedure requires that the unpowered cut be extracted with a switchboat and allows the tow to re-form on an extended guide wall. To take full advantage of this benefit requires that the tow selection policy be a series of tow lockages from the same pool, thus allowing the re-formation to occur while the lock is being reversed to pick up the following vessel. The other primary tow processing procedure, RTS, requires tows to approach the lock already configured for immediate entry without refleeting. This requires that tows use switchboats or that towboats assist each other to move portions of tows that are too large to be locked in a single chambering. Any tow breakdown and re-forming must be completed at facilities completely clear of the lock facilities.

69. From this discussion the significance of the tow approach and exit times can be determined. Figures 23 and 24 present the average monthly times for exchange and turnback approaches to the main and auxiliary chambers, respectively. One can readily observe the wide fluctuations in these times from month to month. Generally, one can observe that doubles and setover lockages require more approach time than single lockages for an exchange type approach. Single other lockages require a minimum amount of approach time. One can readily observe the time advantage of turnback approaches; however, there is much more scatter in the turnback approach times for the auxiliary chamber. Much of the variation observed in the times for auxiliary chambers is probably due to small sample sizes, especially for the single, setover, knockout, and multicut types of lockages. In addition, the auxiliary chamber is located toward the river and tows approaching this chamber are more susceptible to the outdraft currents at the ends of the approach walls; therefore the approach times are going to be much more affected by changing flow conditions than those in the main chamber.

70. The monthly average exchange and turnback exit times recorded for the main and auxiliary chambers at L&D 26 are also displayed in Figures 25 and 26. Again, major variations in these average times can be observed from month to month, especially for the auxiliary chamber. Much of the variations observed for the auxiliary chamber again is due to the small sample sizes available for computing these averages. One can readily observe the distinct advantage of the single lockage exit over the double, multicut, and setover exits, reflecting the time requirements for the tow re-formation operations. The additional time required for the change in average processing times of the individual components is relatively small, about 6 min for doubles. However, the increase in the average processing time for all lockages was very large, about 28 min. This was due to the increase of multicut lockages from 18 percent of all lockages in March to 44 percent in April (Figure 22). During July, August, and September, the average processing times dropped drastically due to a sharp reduction in the percentage of multicut lockages, a reduction in doubles, and a large increase in single other

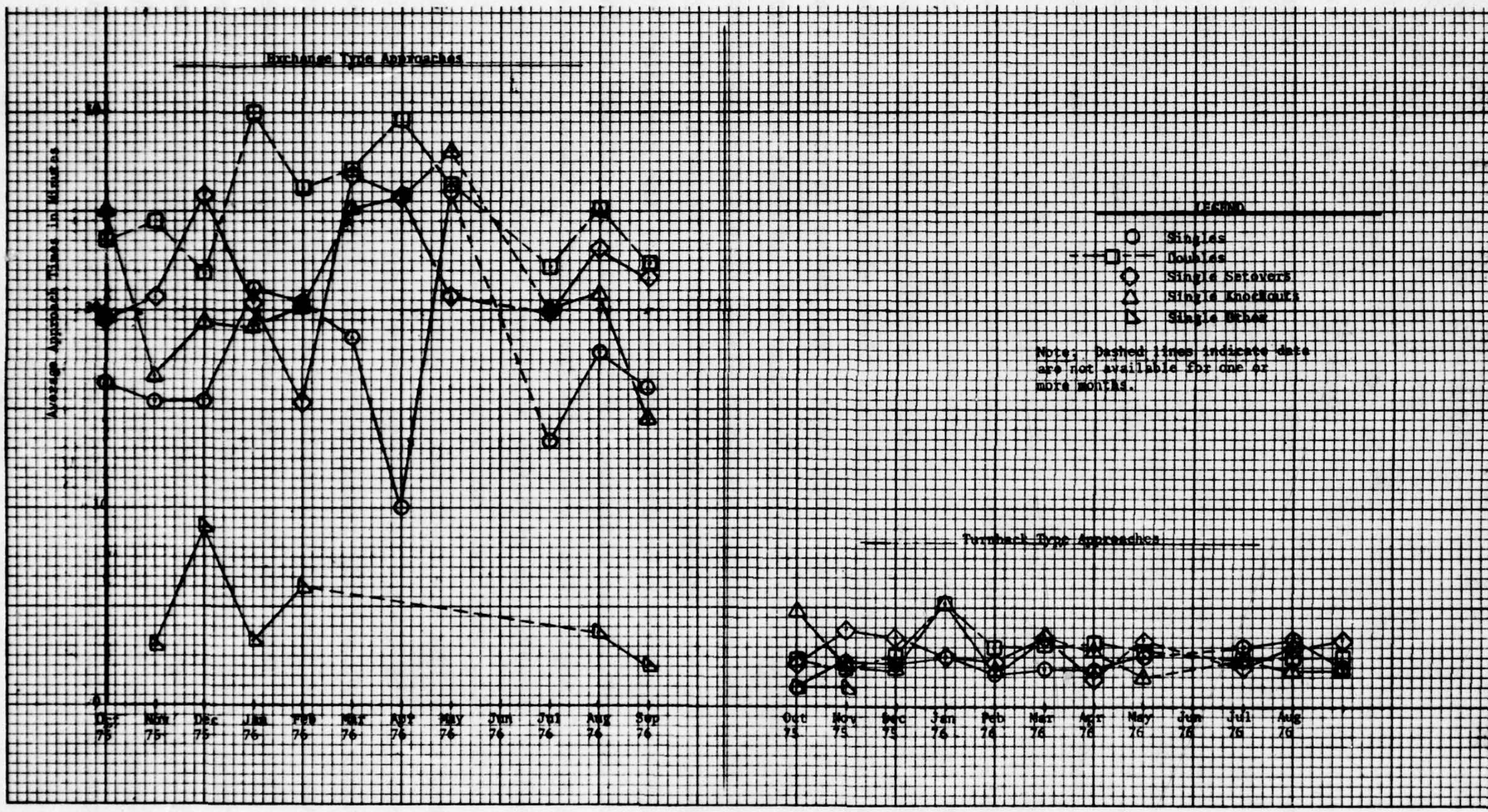


Figure 23. Average exchange and turnback approach times L&D 26 main chamber

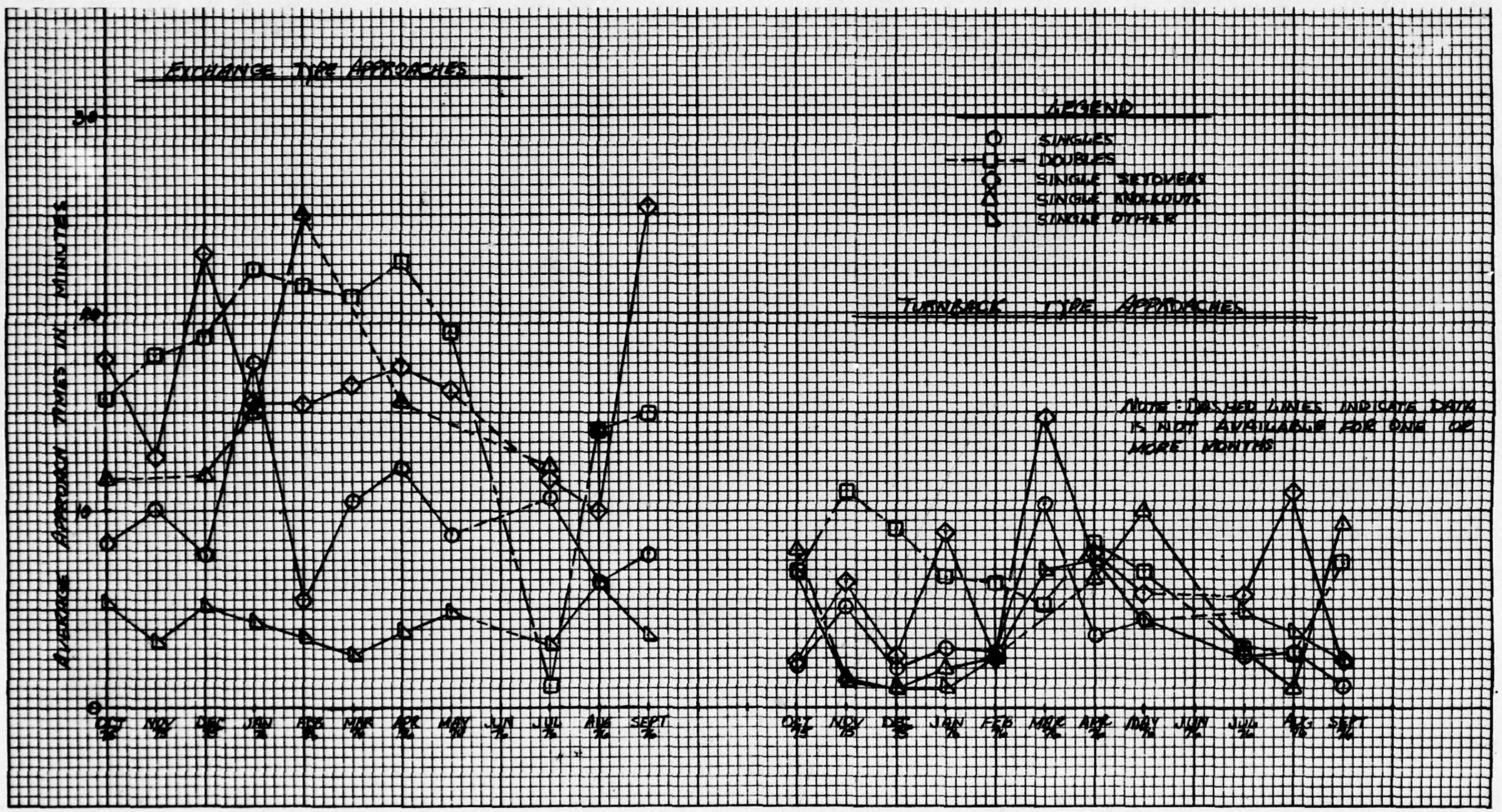


Figure 24. Average exchange and turnback approach times L&D 26 auxiliary chamber

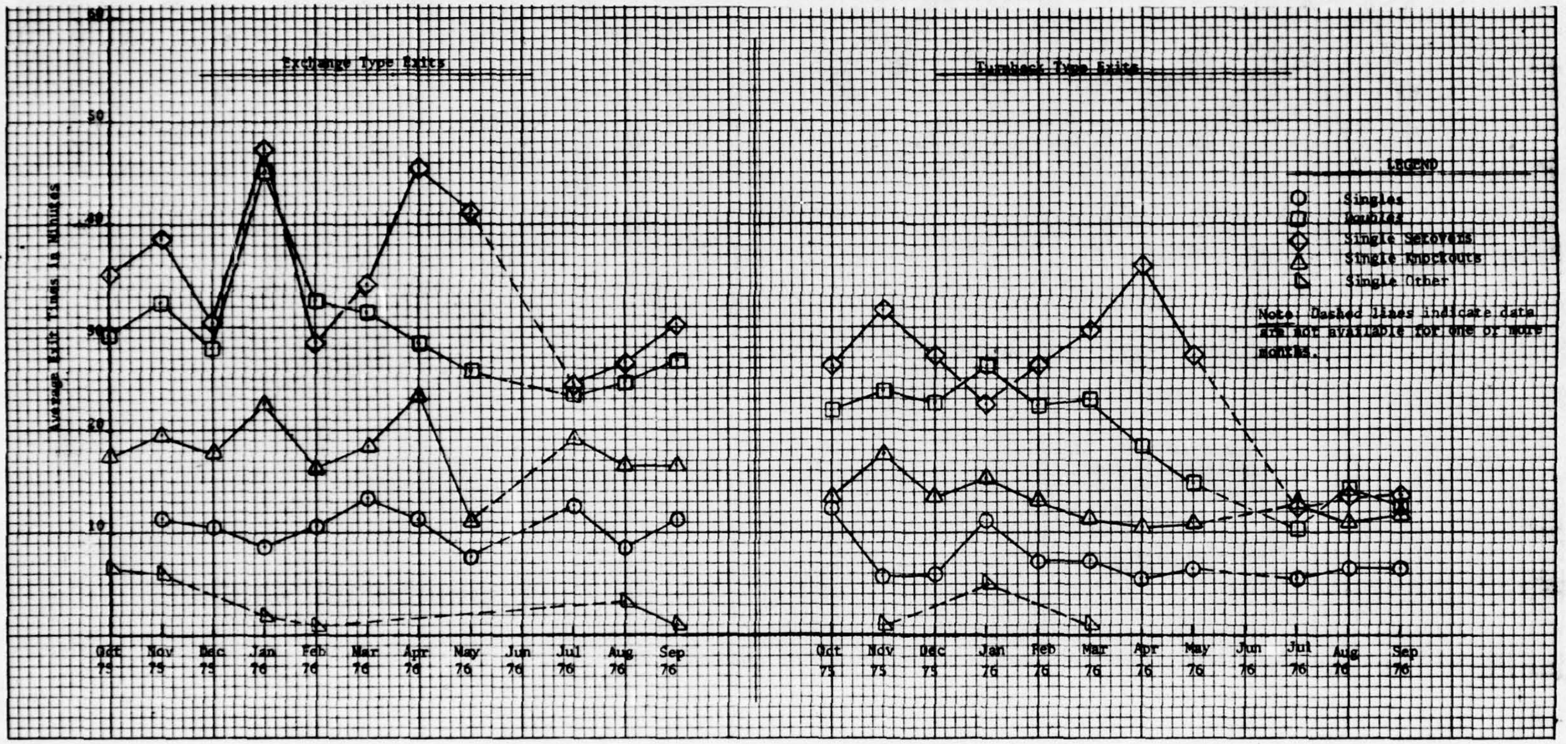


Figure 25. Average exchange and turnback exit times L&D 26 main chamber

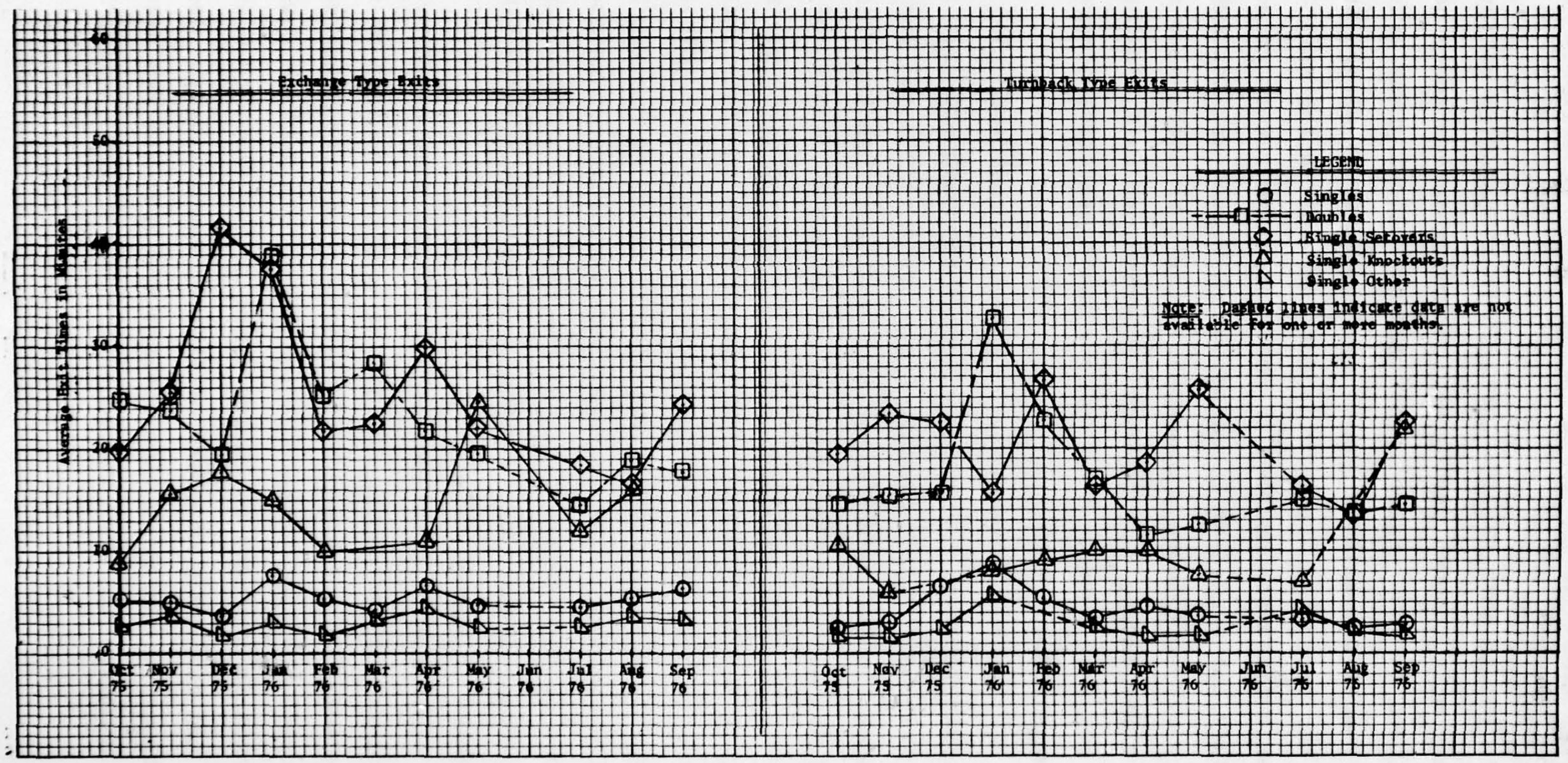


Figure 26. Average exchange and turnback exit times L&D 26 auxiliary chamber

vessel lockages (this lockage type involves recreation craft and lightboats).

71. As noted earlier, the IC lock operating policy was initiated for the main chamber during May following an emergency condition and was continued to some degree in the months following May. This lockage policy does not allow a tow to re-form until it clears the lock chamber; thus the reconfiguring time is not included in the exit time for a tow. The exit times for doubles in the main chamber were reduced during May and July but tended to increase during August and September as the IC policy was more loosely observed. Single setovers also decreased their exit times during July through September, as well, indicating that they also began to observe this policy. This reduction occurred in both exchange and turnback type exits.

72. When the capacity of a lock is computed using the RTS tow processing policy, the single lockage approach and exit times become very critical. These lockage types are a very small percentage of the lockages (in the main chamber they are less than 5 percent of all lockages) and when the times are determined as a function of direction and approach or exit type, the number of observed cases becomes very small. Thus, in determining the lock capacities it was felt that the lockage times should be based on the annual average times. Since only the average time value and the number of samples in a given month were readily available, the average times were computed as the sum of the product of the average time and the number of observations included in the average divided by the total observations. These times are included in Tables in Appendix C.

73. A more detailed analysis of the time saved by eliminating tow breakdown and refleeting inside the lock can be made by comparing the increased lock entry and exit times for tows requiring such an operation with the same times for straight single lockage tows. Such an analysis is included in Tables 9 and 10 for fleeting operations in the main and auxiliary chambers of L&D 26, respectively. Generally speaking, the fleeting operation time savings are greatest for setover lockages, then doubles, and then knockouts in that order. Refleeting times are

Table 9

Analysis of Fleeting Operations During Lockage
L&D 26

Main Chamber

Month	Breakdown						Refleeting					
	Up Direction			Down Direction			Up Direction			Down Direction		
	Double	Setover	Knockout	Double	Setover	Knockout	Double	Setover	Knockout	Double	Setover	Knockout
Oct 75	3.0	10.0	5.0	10.0	22.7*	9.2	16.5	23.9	9.0	23.5	32.3*	16.5
Nov 75	7.8	14.9	7.9	9.7	15.4*	6.6	18.7	27.9	11.1	18.3	17.0*	8.7
Dec 75	7.6	14.5	9.3	7.4	9.4*	8.3	13.9	21.7	7.6	15.0	13.7*	6.5
Jan 76	8.4	17.3	7.2	11.0	15.0*	11.8	19.9	25.7	7.2	22.0	14.7*	7.2
Feb 76	5.3	11.5	7.4	9.1	10.7*	6.5	18.9	10.8	5.3	16.1	10.8	7.1
Mar 76	5.3	11.2	5.8	7.5	15.4	4.0	15.1	24.1	3.9	17.4	15.0	4.0
Apr 76	6.3	16.6	6.9	9.1	16.3*	10.5	13.3	32.0	12.0	14.7	27.6*	4.0
May 76	5.9	12.8	5.2	6.1	10.9*	6.5	8.5	26.1	4.0	12.1	20.8*	5.0
Jul 76	5.2	14.5	8.3	7.2	8.3	5.8	3.1	7.6	3.4	7.1	9.2	11.2
Aug 76	6.6	17.1	7.2	7.9	10.6	5.1	8.1	11.5	6.3	10.4	7.4	5.2
Sep 76	5.4	14.4	5.1	8.2	12.1	6.8	7.3	15.1	5.5	8.0	9.1	6.6
Avg	6.1	14.1	6.9	8.5	12.3	7.4	13.0	20.6	6.4	15.0	16.2	7.5

Source: PMS Data

*Indicates sample size less than or equal to 5.

Table 10

Analysis of Fleeting Operations During Lockage
L&D 26

Auxiliary Chamber

Month	Breakdown								Refleeting							
	Up Direction				Down Direction				Up Direction				Down Direction			
	Double	Multicut	Setover	Knockout	Double	Multicut	Setover	Knockout	Double	Multicut	Setover	Knockout	Double	Multicut	Setover	Knockout
Oct 75	12.1	6.7	16.6	4.5*	6.7	7.0	13.9	8.6	17.8	16.0	20.5	6.9*	15.2	19.1	8.7	4.3
Nov 75	13.1	6.2	12.9	10.5*	7.5	4.2	10.1	12.5*	19.6	20.4	23.9	20.9*	14.0	22.8	10.9	7.6*
Dec 75	7.8	20.0*	12.7	7.8*	6.0	4.5	9.6	13.7*	9.8	7.3*	17.7	11.0*	10.0	22.5	16.2	8.6*
Jan 76	10.9	5.1	12.0	11.8*	8.5	9.9	12.5	5.4*	40.5	40.0	29.9	11.7*	16.1	38.0	10.8	.9*
Feb 76	13.9	5.9	15.2	12.9*	8.9	6.7	8.6	6.9*	26.9	29.1	24.0	6.1*	12.0	29.3	6.1	2.4*
Mar 76	10.3	8.3	13.1	--	5.2	5.2	7.1	6.1*	15.1*	19.1	18.3	--	13.6	16.9	4.9	5.7*
Apr 76	10.0	6.9	17.0	8.9*	7.2	7.9	12.1	7.4	10.9	15.4	21.5	4.1*	9.3	22.2	13.2	9.6
May 76	13.2	9.1	14.4	13.8*	7.6	5.6	8.2	9.6*	13.6	10.3	21.7	20.5*	10.7	21.6	6.1	3.9*
Jul 76	9.4	10.8	18.2	--	7.1	3.9*	10.8	7.1*	11.7	11.3	21.2	--	8.8	10.3*	6.9	5.1*
Aug 76	9.7	12.4	19.9	13.3*	6.8	6.0	9.9	13.5*	10.4	16.4	18.1	17.5*	10.6	.1	7.7	8.3*
Sep 76	10.7	5.9	12.8	9.3*	5.2	5.4	9.7	27.5*	11.7	13.5	17.9	15.0*	9.8	12.6	6.6	27.8*
Avg	11.0	8.9	15.0	10.3	7.0	6.0	10.2	10.8	13.4**	14.4**	21.3	12.6	11.8	20.7	8.9	7.7

Source Data: PMS Data.
* Indicates sample size less than or equal to 5.
** Average not including January and February 1976.

greater than breakdown times. These times correspond well with those observed by Peat, Marwick, Mitchell, and Co. during the switchboat tests. Again, fleeting times for setover and knockout types of lockages vary considerably, primarily due to small sample sizes, especially in the down direction. Refleeting operations for upbound tows in the auxiliary chamber increased very significantly during January and February, apparently due to ice conditions.

74. The process of lock reversal without a tow in the chamber is called swing-around or turnback and is important when comparing lock operating policies, particularly for policies that perform several lockages in the same direction sequentially. Table 11 presents observed monthly average times for the main and auxiliary chambers at L&D 26. The times are relatively constant except during January 1976 for the main chamber and January and February 1976 in the auxiliary chamber. Chamber emptyings appear to take considerably longer during these months, probably due to ice conditions. No explanation is available for the apparent increased swing-around times in the auxiliary chamber during April 1976.

75. In determining the lock capacity, an adjustment is made to the total available time during the analysis period for time when the lock is unavailable due to equipment malfunctions, accidents, weather, or other causes and due to time spent processing vessels other than tows, namely recreation craft and lightboats. In the DM11 report, an adjustment for downtime of 2 percent was made based on long-term observed history of time lost in the main chamber. During the L&D 26 reanalysis, an analysis was made of PMS stall data during 1976. This resulted in an average lost time of 2.9 and 1.6 percent (see Tables 12 and 13) in the main and auxiliary chambers, respectively. Thus, the average lost time factor of 2 percent seems to remain a reasonable estimate for L&D 26.

76. Another adjustment that is required in determining the total time available for locking tows is a reduction for noncommercial lockages, i.e., lockages that do not involve tows with barges. To adjust for this factor, a weighted average lockage time for such lockages and

Table 11

Monthly Variations in Average Swing-around Times

L&D 26

Month	Main Chamber		Auxiliary Chamber	
	Up Direction	Down Direction	Up Direction	Down Direction
Oct 75	13	14	5	7
Nov 75	12	14	7	6
Dec 75	11	11	3	5
Jan 76	12	19	8	10
Feb 76	13	14	6	10
Mar 76	11	11	4	3
Apr 76	10	11	10	8
May 76	12	12	7	6
Jul 76	13	14	4	4
Aug 76	13	13	3	5
Sep 76	14	14	6	5
Avg	12.1	13.4	5.7	6.3

Source: PMS Data

Table 12

Analysis of Stall Conditions

Lock & Dam 26 - Main Chamber - 1976

Percent of Available Time

Stall Condition	Stall Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Weather														
Fog	A	0.0	0.2	0.8	0.0	0.1		0.0	0.0	0.0		0.3	0.0	0.1
Rain	B	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Sleet	C	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Snow	D	0.4	0.0	0.8	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.1
Wind	E	0.2	0.0	*	0.0	0.0		0.0	0.0	0.0		0.0	0.0	*
Surface														
Ice	H	0.5	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	*
River Current	I	0.0	0.0	0.2	0.0	0.1		0.0	0.0	0.0		0.0	0.0	*
Flood	J	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Tow														
Interference	K	0.3	0.0	0.1	0.1	0.0		0.1	0.0	*		0.1	0.0	0.1
Tow Malfunction	L	0.0	0.1	0.1	9.7	0.0		0.4	0.0	0.1		0.1	0.0	1.1
Tow Staff Elsewhere	M	0.0	0.1	*	*	0.3		0.0	0.3	0.3		0.0	0.0	0.1
Lock							NOT AVAILABLE				NOT AVAILABLE			
Debris in Lock	Q	0.0	0.3	0.2	0.0	0.0		*	0.0	*		0.0	0.0	0.1
Hdwr Malfunction	R	0.0	0.0	0.1	0.0	0.0		0.2	0.1	0.1		0.1	0.1	0.1
Staff Elsewhere	S	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Maintenance	T	0.6	0.1	2.4	0.0	0.2		0.1	*	0.3		1.9	0.0	0.6
Other														
Tow Detained by Corps	V	0.0	0.0	0.5	1.8	41.9		0.0	0.7	0.0		0.0	0.0	4.5
Collision	W	0.2	0.0	0.0	0.0	0.0		0.1	0.0	0.0		0.0	0.0	*
Vehicular	X	0.1	0.2	1.0	0.7	0.4		0.2	0.5	0.3		0.6	0.0	0.4
Other	Z	1.2	0.0	0.8	0.6	0.2		0.6	0.6	*		0.1	0.0	0.4
Uncoded		0.1	0.0	0.0	0.0	0.0		0.1	*	*		0.0	0.0	*
TOTAL		3.7	1.0	7.0	12.8	43.5		1.8	2.2	2.2		3.2	0.0	7.7**

Source: PMS Data

*Less than 0.1 percent.

**Ignoring the May stall, the average stall would be 3.8.

Table 13

Analysis of Stall Conditions

Lock & Dam 26 - Auxiliary Chamber - 1976

Percent Available Time

Stall Condition	Stall Code	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg
Weather														
Fog	A	0.0	0.9	0.0	0.0	0.0		0.0	0.0	0.0		0.2	0.0	0.1
Rain	B	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Sleet	C	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Snow	D	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Wind	E	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Surface														
Ice	H	0.5	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.1
River Current	I	0.0	0.0	0.0	0.1	0.0		0.0	0.0	0.0		0.0	0.0	
Flood	J	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	
Tow														
Interference	K	0.0	0.4	0.1	0.2	0.3	NOT AVAILABLE	0.0	0.0	0.1	NOT AVAILABLE	0.1	0.0	0.1
Malfunction	L	0.0	0.0	0.0	0.0	0.1		0.0	0.0	0.0		0.0	0.0	*
Staff Elsewhere	M	0.0	*	0.2	0.3	0.0		0.1	0.0	*		0.2	0.0	0.1
Lock														
Debris-in-lock	Q	0.0	*	0.0	0.0	0.0		0.0	0.1	0.0		0.0	0.0	*
Hdwr. Malfunction	R	0.1	*	0.9	0.0	0.0		0.2	0.0	0.0		0.0	0.0	0.1
Staff Elsewhere	S	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0		0.0	0.0	0.0
Maintenance	T	0.0	0.0	0.0	0.0	0.0		*	0.0	0.9		0.5	0.0	0.1
Other														
Tow Detained by Corps	V	0.0	0.0	0.0	0.1	0.0		0.0	0.1	*		0.0	0.0	*
Collision	W	0.0	0.0	0.1	0.0	*		0.0	0.0	0.0		0.0	0.0	*
Vehicular	X	0.3	0.3	0.1	0.3	0.4		*	0.1	0.2		0.1	0.0	0.2
Other	Z	1.3	0.1	1.6	0.1	0.1		0.2	0.3	0.2		0.6	0.0	0.5
Uncoded		0.0	0.0	0.0	*	0.0		0.1	0.0	0.0		0.0	0.0	*
TOTAL		2.7	2.2	3.1	1.1	0.9		0.5	0.5	1.4		1.6	0.0	1.4

*Less than .1 percent.

the average number occurring during a month throughout the shipping season (April through November) was determined for the auxiliary chamber. These values are shown in Table 14. No adjustment was required for the main chamber as only six of these lockages occurred during the 1976 shipping season.

Table 14

Noncommercial Lockages in Auxiliary Chamber

L&D 26, Mississippi River

Month 1976	Number of Lockages Occurring	Average Time min	No. × Avg Time
April	50	19.4	970
May	70	20.4	1,428
June	NA	NA	NA
July	180	19.5	3,510
August	113	19.2	2,170
September	132	20.0	2,640
October	77	20.8	1,602
November	63	21.3	1,342
Total	685		13,662
Avg	98		19.94

Lock Utilization

77. Table 15 presents the relation of tonnage, utilization, and empty barge percentages for the main and auxiliary chambers and for the lock as a unit. The utilization is based upon the use of the lock to service vessels and includes all of the time from the beginning of lockage of the first cut to the end of lockage of the last cut and the time for all turnbacks between lockages when the vessels locking immediately following one another were traveling in the same direction. Table 15 reveals that the main chamber was used consistently at a level of 93 percent or higher, except for the months of December 1975 and April 1976. This is a very high utilization rate. In December the traffic level was exceptionally low. In April, use of the main chamber was

Table 15

Lock Utilization, L&D 26

	Main				Auxiliary				Both			
Month	Tonnage M tons	Percent Utilization	Percent Stall	Percent Empty Barges	Tonnage M tons	Percent Utilization	Percent Stall	Percent Empty Barges	Tonnage M tons	Percent Utilization	Percent Stall	Percent Empty Barges
Oct 75	4538	98.6		26.4	1052	75.6		45.4	5590	87.1		30.8
Nov 75	4021	100.0		32.7	1308	81.9		39.0	5329	91.7		34.2
Dec 75	3173	88.1		43.5	424	40.0		51.1	3596	64.0		45.5
Jan 76	2415	95.3	3.7	40.6	483	55.1	2.7	47.8	2899	76.4		41.8
Feb 76	3425	100.0	1.0	38.0	945	76.9	2.2	47.4	4370	88.7		40.1
Mar 76	4060	93.1	7.0	36.2	600	47.5	3.1	46.2	4660	70.3		37.7
Apr 76	3672	73.2	12.8	35.1	1457	77.6	1.1	36.4	5129	75.0		35.5
May 76	4989	99.0	43.5	36.9	1055	66.8	0.9	45.5	6044	83.0		38.5
Jun 76						Not available						
Jul 76	4365	95.0	1.8	38.1	498	48.8	0.5	57.4	4863	72.0		40.6
Aug 76	3946	96.4	2.2	38.0	550	45.6	0.5	51.1	4496	71.0		39.9
Sep 76	4077	95.8	2.2	32.5	551	47.9	1.4	51.7	4628	71.9		35.4
Avg	3880	94.0		36.3	811	60.3		47.2	4691	77.4		38.2

Source: PMS data.

curtailed following an accident at the lock. Utilization of the auxiliary chamber was also exceptionally high during the sample period.

78. Since the main chamber is so heavily utilized, the auxiliary chamber must normally absorb any extra traffic load. Care must be exercised to clarify the tonnage/utilization relation, since the percentage of empty barges locked is also very significant. During October 1975, one of the largest tonnage levels passed through L&D 26, yet utilization of both lock chambers was less than in November 1975, since more tows were locked as the result of an increase in return empty barges.

79. Likewise, variations in lockage component processing times also influence lock utilization. For example, more tonnage passed through L&D 26 during May 1976 than either October or November 1975 even though there was a higher percentage of empty barge movements. A change in lock operating policy caused this when the more efficient IC procedure was employed in May to alleviate the traffic congestion accumulated during April.

PART V: ANALYSIS OF CAPACITY

New Data--L&D 26

80. Based on an analysis of 1975-76 conditions at L&D 26, the findings support that traffic characteristics have changed sufficiently from those used to determine the lock capacity in earlier studies to warrant a reanalysis of the lock capacity using these traffic characteristics. In addition, a long-term record of new data on the lockage component times was available to provide a more accurate service time data base and data for one month were available describing locking times under the IC lock operating policy. These data were reduced to the form required by the lock capacity computation procedure described earlier.

81. The annual commodity movement pattern observed during 1976 was the most recent data available for analysis of lock capacity. These data reflected the changes that had occurred in commodity mix. The percent distribution of commodities by commodity group is presented in Table 16. Since a typical month in the shipping season was found to carry 9.22 percent of the annual traffic, the lock capacity determined for a 30-day period was multiplied by 1/0.0922 or 10.85 to obtain the annual capacity. The capacity of L&D 26 was also determined based on the distribution of commodities observed during a peak month, May 1976. During this month an unusually large percentage of the tonnage moved was grain (Table 17).

82. The characteristics of the 1976 fleet served by L&D 26 were very difficult to define using the available data. Tows with integrated barges and mixed barge types could not be automatically classified by a computer because of the complicated decision-making processes involved. Thus, analysis of fleet characteristics had to be partially determined by hand. Since data for the full year were too voluminous, selected data were used to determine the tow characteristics. The general annual characteristics of the fleet were determined and compared with the monthly characteristics. The data for March 1976 were found to be very close to the general characteristics of the annual traffic (Table 18);

Table 16

1976 Annual Commodity Distribution

L&D 26, Mississippi River

COMMODITY NO.	COMMODITY NAME	COMMODITY MATRIX UP	DOWN	PERCENT TOTAL
1	GRAIN	.19	50.37	50.55
2	COAL	9.27	.12	9.39
3	PETROLEUM	9.68	3.04	12.72
4	GRVL, SND,A	.47	.66	1.13
5	IRON & STEE	2.35	2.30	4.65
6	CHEMICALS	13.80	.59	14.40
7	OTHER & MIS	1.93	5.22	7.16
	TOTAL	37.71	62.29	100.00

Table 17

May 1976 Commodity Distribution

L&D 26, Mississippi River

COMMODITY NO.	COMMODITY NAME	COMMODITY MATRIX UP	DOWN	PERCENT TOTAL
1	GRAIN	1.27	53.60	54.86
2	COAL	9.15	.12	9.27
3	PETROLEUM	10.07	2.66	12.73
4	GRVL, SND,A	.66	.54	1.20
5	IRON & STEE	1.91	1.68	3.58
6	IND CHEMICA	7.90	.44	8.35
8	OTHER &MISC	8.69	1.31	10.01
	TOTAL	39.65	60.35	100.00

Table 18

Tow Characteristics Comparison L&D 26, Mississippi River

	Average 1976	March 1976	Percent Difference
Percent empty	38.1	37.7	-1.1
Barges/tow	7.4	7.3	-1.4
Barges/lockage	4.4	4.5	+2.3
Tons/tow	6.8	6.6	-2.9
Tons/lockage	4.1	4.1	0.0
Tons/barge	916.0	906.0	-1.1
Lockages/tow	1.7	1.6	-5.9

therefore the month of March was chosen to represent the average annual traffic. In addition, the traffic characteristics observed during the peak traffic month of May 1976 were used in determining L&D 26 capacity.

83. Tables 19 and 20 show the commodity/barge/tow relations for 1976 and for the month of May. The primary difference in the distribution between commodity types and barge types is the distribution of petroleum and chemicals among the different sized tank barges. In the 1976 data, it was not possible to distinguish between agricultural and industrial chemicals being carried in the different barge types. Therefore, no distinction between chemical classes was made in the 1976 commodity distribution to the barge types.

84. The average loads carried by the various barge types was slightly different between the two cases. In all cases only the petroleum and chemical barges were considered to be dedicated since the possibility of contamination is high and the resulting cleanup process is costly.

85. One of the more critical tow characteristic descriptions is the distribution of tow sizes in terms of number of barges per tow. Tables 21 and 22 present the tow size distribution for the 1976 and May fleet characteristics, respectively. The lockage types required to process these tows in the present lock's main and auxiliary chambers and a new 1200-ft chamber are also identified. One can readily observe the increase in tow sizes of the predominant tow type (Hopper Jumbos) toward a nearly 50 percent concentration of 15 barge tows. There are also corresponding increases in most of the petroleum and chemical tank tow types.

86. When all of the tows are assumed to lock through a single large chamber and the tow distribution continues to contain small tows, then a tow processing policy that would allow the small tows to be locked together (multivessel lockages) should be considered. Such events occur as the present tow fleet is processed in a single chamber 1200-ft lock. At present, the methodology being used to determine lock capacity is not able to estimate directly the effect of multivessel lockages; therefore, an approach was used in which the distribution of

Table 19

Average 1976 Commodity/Barge/Tow Relations

L&D 26, Mississippi River

COMMODITY DISTRIBUTION BY BARGE TYPE
(PERCENT)

COMMODITY NO.	NAME	BARGE TYPES 1	2	3	4	5	6	7	TOTAL
1	GRAIN	100	0	0	0	0	0	0	100
2	COAL	100	0	0	0	0	0	0	100
3	PETROLEUM	0	18	54	28	0	0	0	100
4	GRVL, SND,A	100	0	0	0	0	0	0	100
5	IRON & STEE	100	0	0	0	0	0	0	100
6	CHEMICALS	0	0	0	0	51	35	14	100
7	OTHER & MIS	100	0	0	0	0	0	0	100

BARGE DATA

BARGE TYPE NO.	NAME	AVERAGE BARGE LOAD	DEDICATED EQUIP.(%)	ASSOCIATED TOW TYPE
1	HOPPER JUMBO	1338	0	1
2	PETROL JUMBO	1417	100	2
3	PET TANK M	2400	100	3
4	PET TANK L	2649	100	4
5	CHEM JUMBO	1346	100	5
6	CHEM TANK M	1908	100	6
7	CHEM TANK L	2604	100	7

Table 20

May 1976 Commodity/Barge/Tow Relations

L&D 26, Mississippi River

COMMODITY DISTRIBUTION BY BARGE TYPE
(PERCENT)

COMMODITY NO.	NAME	BARGE TYPES 1	2	3	4	5	6	7	TOTAL
1	GRAIN	100	0	0	0	0	0	0	100
2	COAL	100	0	0	0	0	0	0	100
3	PETROLEUM	0	6	41	53	0	0	0	100
4	GRVL, SND,A	100	0	0	0	0	0	0	100
5	IRON & STEE	100	0	0	0	0	0	0	100
6	IND CHEM	0	0	0	0	48	31	21	100
7	AGR CHEM	0	0	0	0	100	0	0	100
8	OTHER & MIS	100	0	0	0	0	0	0	100

BARGE DATA

BARGE TYPE NO.	NAME	AVERAGE BARGE LOAD	DEDICATED EQUIP.(%)	ASSOCIATED TOW TYPE
1	HOPPER JUMBO	1326	0	1
2	PETROL JUMBO	1307	100	2
3	PET TANK M	2053	100	3
4	PET TANK L	2740	100	4
5	CHEM JUMBO	1350	100	5
6	CHEM TANK M	1821	100	6
7	CHEM TANK L	2449	100	7

Table 21

Average 1976 Tow Size Distribution

L&D 26, Mississippi River

TOW TYPE NO.	NAME	NO. BRGS PER TOW	DIST. (%)	LOCKAGE TYPE MAIN	LOCKAGE TYPE AUX	1200'
1	HOPPER JUMBO	2	6	1	1	1
		3	7	1	1	1
		4	4	1	2	1
		6	9	1	2	1
		8	6	44	3	1
		9	8	2	3	1
		10	2	2	4	1
		12	16	2	4	1
		14	10	2	5	1
		15	32	2	5	1
2	PETRO JUMBO	2	33	1	1	1
		3	17	1	1	1
		14	16	2	5	1
		15	34	2	5	1
3	PETRO TANK M	1	2	1	1	1
		2	17	1	44	1
		3	22	44	2	1
		4	40	1	2	1
		5	3	2	3	1
		6	3	2	3	1
		8	8	2	4	1
		9	2	3	5	1
		10	2	3	5	2
		11	1	3	6	2
4	PETRO TANK L	2	33	1	44	1
		3	29	44	2	1
		4	38	2	3	1
5	CHEM JUMBO	2	25	1	1	1
		4	13	1	2	1
		10	12	2	4	1
		15	50	2	5	1
6	CHEM TANK M	1	6	1	1	1
		2	12	1	44	1
		3	16	44	2	1
		4	16	1	2	1
		5	24	2	3	1
		6	8	2	3	1
		8	8	2	4	1
		10	8	3	5	2
7	CHEM TANK L	2	38	1	44	1
		3	37	44	2	1
		4	19	2	3	1
		6	6	2	4	1

Table 22

May 1976 Tow Size Distribution

L&D 26, Mississippi River

TOW DISTRIBUTION DATA						
TOW TYPE NO.	NAME	NO. BRGS PER TOW	DIST. (%)	LUCKAGE TYPE MAIN	LUCKAGE TYPE AUX	1200'
1	HOPPER JUMBO	2	7	1	1	1
		4	9	1	2	1
		6	8	1	2	1
		8	4	44	3	1
		10	9	2	4	1
		12	16	2	4	1
		15	47	2	5	1
2	PETROL JUMBO	1	0	1	1	1
		2	20	1	1	1
		3	0	1	1	1
		4	0	1	2	1
		5	0	1	2	1
		6	20	1	2	1
		8	0	44	3	1
		10	20	2	4	1
		12	20	2	4	1
		15	20	2	5	1
3	PETROL TANKM	1	3	1	1	1
		2	17	1	44	1
		3	15	44	2	1
		4	34	1	2	1
		5	15	2	3	1
		6	5	2	3	1
		7	0	2	4	1
		8	3	2	4	1
		9	6	3	5	1
		10	2	3	5	2
4	PETROL TANKL	1	2	1	1	1
		2	32	1	44	1
		3	7	44	2	1
		4	45	2	3	1
		5	5	2	3	1
		6	7	2	4	1
		7	2	2	4	1
5	CHEM JUMBO	1	5	1	1	1
		2	11	1	1	1
		3	5	1	1	1
		4	5	1	2	1
		5	11	1	2	1
		6	0	1	2	1
		8	5	44	3	1
		10	0	2	4	1
		12	5	2	4	1
		15	53	2	5	1
6	CHEM TANK M	1	2	1	1	1
		2	15	1	44	1
		3	25	44	2	1
		4	25	1	2	1
		5	10	2	3	1
		6	3	2	3	1
		7	5	2	4	1
		8	0	2	4	1
		9	0	3	5	1
		10	15	3	5	2
7	CHEM TANK L	1	0	1	1	1
		2	35	1	44	1
		3	50	44	2	1
		4	5	2	3	1
		5	5	2	3	1
		6	5	2	4	1
		7	0	2	4	1

the tow sizes was modified to reflect the occurrences of multivessel lockages. The tow size distribution was modified to reflect the assumption that queues at the lock would be large enough to accommodate the selection of a small tow that would fit in the lock. Thus, the smaller tows were eliminated and their percentages included in combinations with the larger tows. Using this procedure, the tow size distribution selected to represent multivessel operations at a single 1200-ft lock is shown in Table 23

87. The standard lockage times used in this analysis study for the present locks were based on the average annual processing times determined as a weighted average of the months in the shipping season. These times are shown in Table 24. The lockage times for the single 1200-ft chamber were derived from observed lockage times at locks with similar characteristics of the same size and are shown in Table 25. These locks were Pike Island, New Cumberland, Racine, and Belleville on the Ohio River. These are the same times used in the simulation study reported in DM11. The same lock timings were used for a given chamber whether it was being considered as a single chamber facility or as part of a dual chamber lockage facility.

88. In November 1976, a lock operating policy was initiated at L&D 26 that required a tow to refleet clear of the lock. This was usually accomplished with the assistance of another towboat. The IC policy reduces considerably the time required for double and setover lockages. The observed times for lockage components during November 1976 were used to analyze the effects of this policy on the lock capacity determination (see Table 26).

89. The times that the lock is unavailable to service tows as the result of maintenance, accidents, weather, and the demands of recreation vessels and lightboats are accounted for by using annual and seasonal average values, as presented in the discussion of field data. Historically, the lock is unavailable about 2 percent of the time. The time spent processing recreational vessels and lightboats is considered to remain constant until capacity is reached; and all of these lockages are assumed to take place in the auxiliary chamber, if one is available at the lock site.

Table 23

Tow Size Distribution with Multivessel Lockages in a Single 1200-ft Chamber

L&D 26, Mississippi River

TOW DISTRIBUTION DATA				
TOW TYPE NO.	NAME	NO. BRGS PER TOW	DIST. (%)	LOCKAGE TYPE MAIN
1	HOPPER JUMBO	10	19	1
		12	34	1
		15	47	1
2	PETROL JUMBO	8	14	1
		10	24	1
		12	31	1
		15	31	1
3	PETROL TANKM	4	5	1
		5	6	1
		6	11	1
		7	28	1
		8	23	1
		9	19	1
		10	8	2
4	PETROL TANKL	4	19	1
		5	38	1
		6	23	1
		7	20	1
5	CHEM JUMBO	8	13	1
		10	24	1
		12	31	1
		15	32	1
6	CHEM TANK M	4	7	1
		5	18	1
		6	27	1
		7	23	1
		8	16	1
		9	9	1
		10	0	2
7	CHEM TANK L	4	23	1
		5	40	1
		6	20	1
		7	17	1

Table 24

Lockage Times, Present Locks

L&D 26, Mississippi River

LOCKING TIME DISTRIBUTION

NO.	LOCKAGE TYPE	DIR	CHAM	APPROACH EXCH.	APPROACH TURN	CHAMBERING	EXIT EXCH.	EXIT TURN
1	SINGLE	U	MAIN	14.9	3.3	22.0	10.7	6.6
		D		16.9	1.6	19.6	10.4	6.4
1	SINGLE	U	AUX.	7.7	3.9	15.4	4.8	3.5
		D		10.6	3.5	15.4	5.2	3.6
2	DOUBLE	U	MAIN	22.9	2.6	75.8	27.4	17.0
		D		24.6	2.4	85.0	30.7	18.2
2	DOUBLE	U	AUX.	14.7	9.3	70.1	23.2	21.6
		D		18.5	5.3	60.6	20.8	14.1
3	TRIPLE	U	MAIN	24.0	7.5	136.8	20.0	5.7
		D		47.5	7.5	136.8	55.0	5.7
3	TRIPLE	U	AUX.	17.4	5.6	151.8	25.3	25.5
		D		25.6	12.4	157.2	30.0	23.2
4	SETOVER	U	MAIN	20.3	3.0	33.7	22.9	17.7
		D		19.8	1.6	28.6	21.4	13.0
4	SETOVER	U	AUX.	15.2	6.0	31.0	23.9	27.0
		D		14.1	3.8	32.5	16.1	12.2
5	MULTIPLE	U	MAIN	14.9	3.3	22.0	10.7	6.6
		D		16.9	1.6	19.6	10.4	6.4
5	MULTIPLE	U	AUX.	7.7	3.9	15.4	4.8	3.5
		D		10.6	3.5	15.4	5.2	3.6
6	TURNBACK	U	MAIN	0.	0.	12.1	0.	0.
		D		0.	0.	13.4	0.	0.
6	TURNBACK	U	AUX.	0.	0.	5.7	0.	0.
		D		0.	0.	6.3	0.	0.

Table 25

Lockage Times, 1200-ft × 110-ft Replacement Lock

LOCKING TIME DISTRIBUTION							
LOCKAGE			APPROACH		CHAMBERING	EXIT	
TYPE	DIR	CHAM	EXCH.	TURN		EXCH.	TURN
SINGLE	U	MAIN	14.9	3.3	22.0	10.7	6.6
	D		16.9	1.6	22.0	10.4	6.4
DOUBLE	U	MAIN	22.9	2.6	70.0	27.4	17.0
	D		24.6	2.4	70.0	30.7	18.2
TRIPLE	U	MAIN	24.0	7.5	118.0	20.0	5.7
	D		47.5	7.5	118.0	55.0	5.7
SETOVER	U	MAIN	21.2	3.0	28.6	22.8	17.7
	D		19.8	1.6	24.4	21.4	13.6
MULTIPLE	U	MAIN	14.9	3.3	22.0	10.7	6.6
	D		16.9	1.6	22.0	10.4	6.4
TURNBACK	U	MAIN	0.	0.	12.1	0.	0.
	D		0.	0.	13.4	0.	0.

Table 26

Lockage Times, Present Locks Using Industry Choice

L&D 26, Mississippi River

LOCKING TIME DISTRIBUTION

LOCKAGE TYPE	DIR	CHAM	APPROACH EXCH.	APPROACH TURN	CHAMBERING	EXIT EXCH.	EXIT TURN
SINGLE	U	MAIN	14.9	3.3	22.0	10.7	6.6
	D		16.9	1.6	19.6	10.4	6.4
SINGLE	U	AUX.	7.7	3.9	15.4	4.8	3.5
	D		10.6	3.5	15.4	5.2	3.6
DOUBLE	U	MAIN	21.6	2.7	69.0	23.5	7.2
	D		21.5	2.4	73.1	25.7	8.4
DOUBLE	U	AUX.	15.7	3.1	56.8	15.2	10.0
	D		18.8	6.1	58.6	17.4	10.7
TRIPLE	U	MAIN	21.6	2.7	105.5	23.5	7.2
	D		21.5	2.4	109.7	25.7	8.4
TRIPLE	U	AUX.	20.5	3.1	134.6	25.2	24.0
	D		16.7	3.7	145.4	25.2	22.6
SETOVER	U	MAIN	18.1	3.5	33.1	20.1	9.3
	D		21.0	1.6	28.1	16.3	14.1
SETOVER	U	AUX.	12.8	8.3	37.0	32.7	27.0
	D		18.9	1.3	26.8	12.4	6.3
MULTIPLE	U	MAIN	14.9	3.3	22.0	10.7	6.6
	D		16.9	1.6	19.6	10.4	6.4
MULTIPLE	U	AUX.	7.7	3.9	15.4	4.8	3.5
	D		10.6	3.5	15.4	5.2	3.6
TURNBACK	U	MAIN	0.	0.	12.1	0.	0.
	D		0.	0.	13.4	0.	0.
TURNBACK	U	AUX.	0.	0.	5.7	0.	0.
	D		0.	0.	6.3	0.	0.

L&D 25 and 27

90. Current lockage data at L&D 25 and 27 were also analyzed, though not in as much depth, to determine changes in traffic and lockage characteristics that might affect the determination of the capacities of these locks. This is particularly significant at L&D 27, since some improvements were made to one of the approach walls which might affect the locking times. Also, with the change in traffic characteristics noticed at L&D 26, similar changes at these adjacent locks would be expected.

91. The seasonal effects of the winter closure of the upper Mississippi River are even more pronounced at L&D 25 than those at L&D 26 (Figure 27). L&D 27 is not as affected by this factor although there remains a dip in the percentage of annual traffic carried in December through February (Figure 28). A monthly average traffic percentage of 11.0 and 8.43 was derived for L&D 25 and 27, respectively. The season used for L&D 25 was March through November and the entire year was used for L&D 27. Annual commodity distributions of the tonnage movements through these locks were obtained from the St. Louis District and are presented in Tables 27 and 28.

92. The average lock processing times for L&D 25 were determined in the same manner as those for L&D 26. These times are presented in Table 29. The average processing times for L&D 27 were determined from those observed during October and November 1976 since construction activities in the lock approach restricted the entry of tows and required special operating conditions prior to this. October 1976 was the first full month of record following completion of these construction activities and resumption of normal lock operations. These times are presented in Table 30.

93. Tow configuration data for L&D 25 were derived based upon tow size data obtained from the St. Louis lockmaster data. Tow size distributions for L&D 25 are shown in Table 31. Since Jumbo hopper tows so predominate the traffic through these locks, this information adequately described the tow sizes and was readily available. L&D 27 traffic

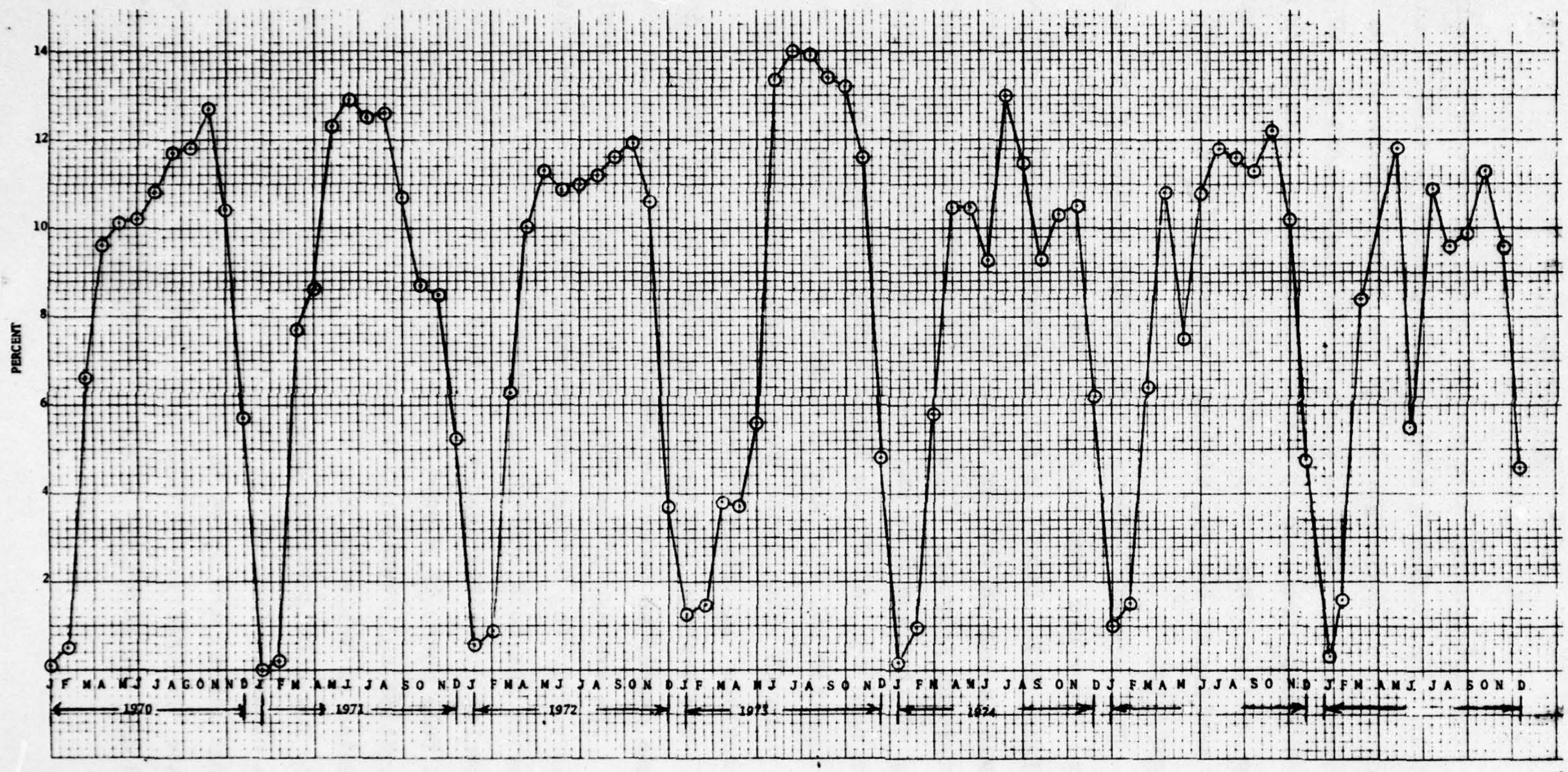


Figure 27. Monthly distribution of commodity movements L&D 25 years 1970-1976

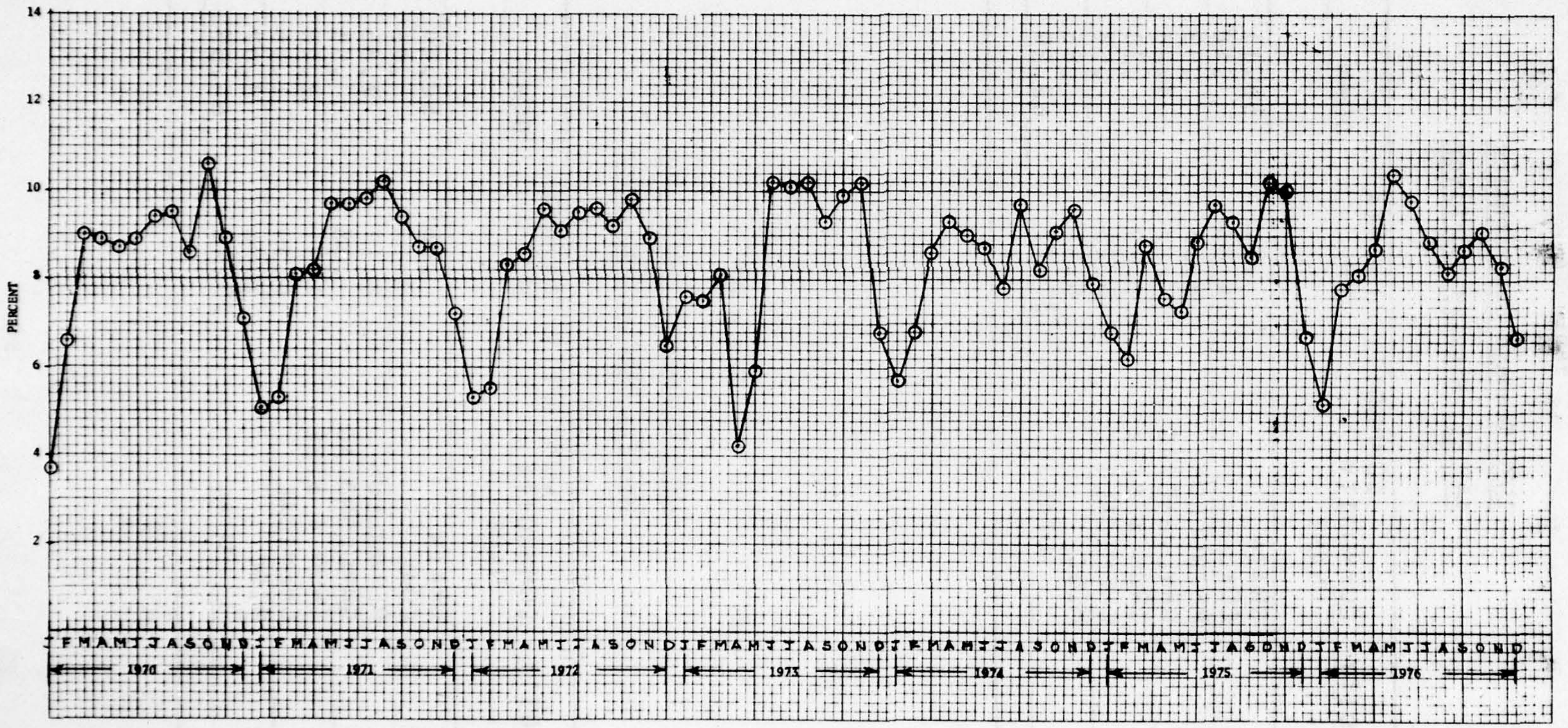


Figure 28. Monthly distribution of commodity movements L&D 27 years 1970-1976

Table 27

1976 Tonnage Distribution

L&D 25, Mississippi River

COMMODITY NO.	COMMODITY NAME	COMMODITY MATRIX UP	DOWN	PERCENT TOTAL
1	GRAIN	.50	56.11	56.61
2	COAL	14.83	.40	15.23
3	PETROLEUM	9.15	.82	9.97
4	GRVL,SND,AG	.67	3.28	3.95
5	IRON & STEE	.79	.30	1.09
6	CHEMICALS	5.25	.53	5.79
7	MISC	6.51	.85	7.36
	TOTAL	37.71	62.29	100.00

Table 28

1976 Tonnage Distribution

L&D 27, Mississippi River

COMMODITY NO.	COMMODITY NAME	COMMODITY MATRIX UP	DOWN	PERCENT TOTAL
1	GRAIN	.66	50.44	51.10
2	COAL	8.13	.46	8.58
3	PETROLEUM	8.17	7.85	16.02
4	GRVL,SND,AG	.38	.53	.91
5	IRON & STEE	1.91	2.06	3.96
6	CHEMICAL	8.34	1.16	9.50
7	MISC	7.86	2.07	9.93
	TOTAL	35.45	64.55	100.00

Table 29

1976 Lockage Times

L&D 25, Mississippi River

LOCKING TIME DISTRIBUTION							
LOCKAGE			APPROACH		CHAMBERING	EXIT	
TYPE	DIR	CHAM	EXCH.	TURN		EXCH.	TURN
SINGLE	U	MAIN	10.9	2.9	15.1	3.9	4.5
	D		13.0	4.2	14.0	4.5	4.3
DOUBLE	U	MAIN	18.3	3.6	67.3	18.0	17.9
	D		26.3	8.4	71.6	21.4	16.4
TRIPLE	U	MAIN	0.	0.	0.	0.	0.
	D		0.	0.	0.	0.	0.
SETOVER	U	MAIN	15.7	3.3	28.0	22.3	20.8
	D		19.1	5.7	22.1	14.1	16.3
MULTIPLE	U	MAIN	0.	0.	0.	0.	0.
	D		0.	0.	0.	0.	0.
TURNBACK	U	MAIN	0.	0.	11.4	0.	0.
	D		0.	0.	10.1	0.	0.

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SENSITIVITY OF BASE DATA IN THE ANALYSIS OF LOCK CAPACITY: A CA--ETC(U)
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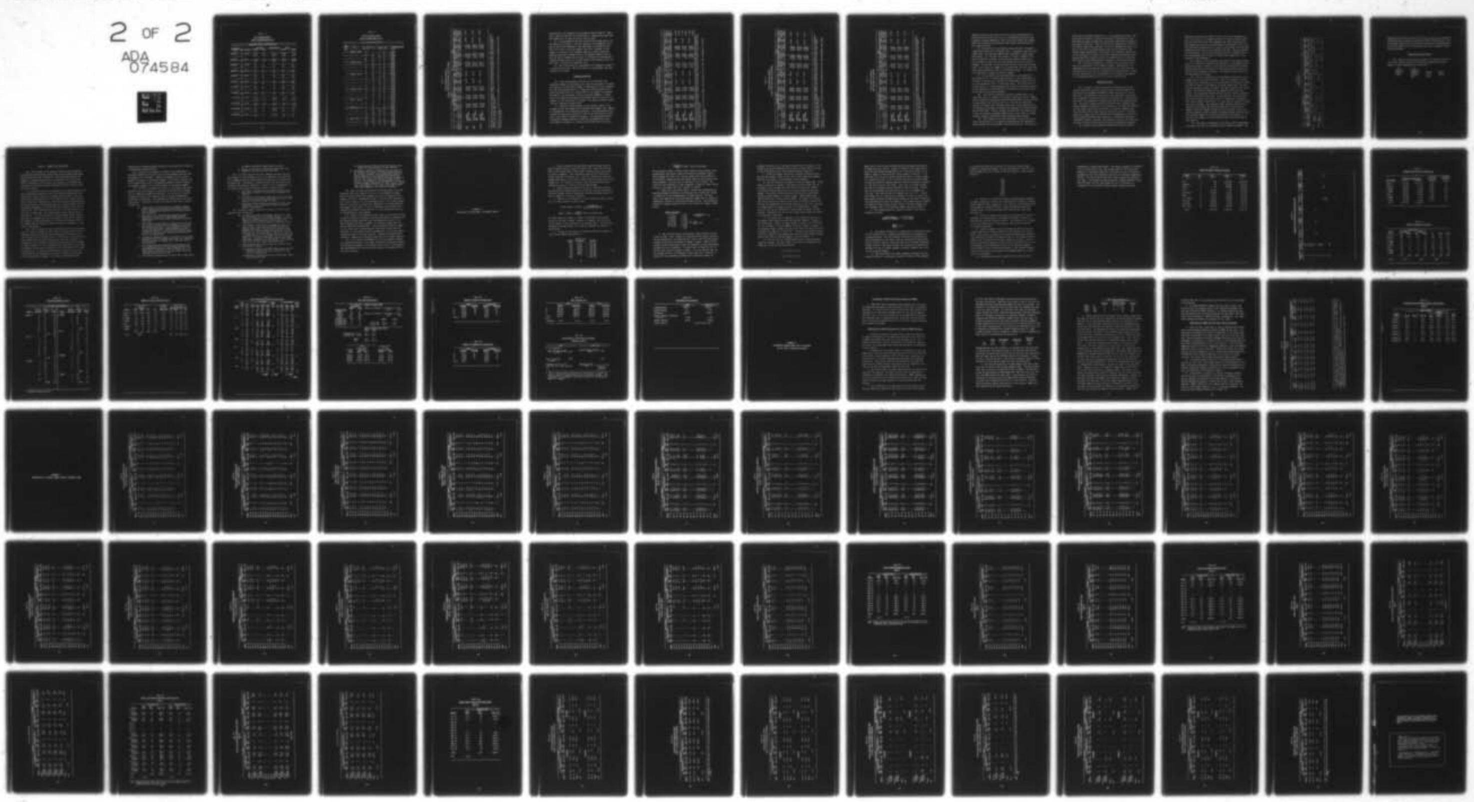

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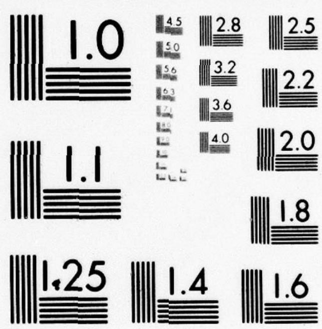

MICROCOPY RESOLUTION TEST CHART

Table 30

1976 Lockage Times

L&D 27, Mississippi River

LOCKING TIME DISTRIBUTION							
LOCKAGE			APPROACH		CHAMBERING	EXIT	
TYPE	DIR	CHAM	EXCH.	TURN		EXCH.	TURN
SINGLE	U	MAIN	14.2	4.9	21.1	9.6	7.7
	D		16.3	4.3	20.5	10.2	8.0
SINGLE	U	AUX.	7.9	3.7	13.9	5.2	4.8
	D		12.7	4.5	15.5	4.7	4.4
DOUBLE	U	MAIN	0.	0.	0.	0.	0.
	D		0.	0.	0.	0.	0.
DOUBLE	U	AUX.	0.	0.	0.	0.	0.
	D		0.	0.	0.	0.	0.
TRIPLE	U	MAIN	0.	0.	0.	0.	0.
	D		0.	0.	0.	0.	0.
TRIPLE	U	AUX.	0.	0.	0.	0.	0.
	D		0.	0.	0.	0.	0.
SETOVER	U	MAIN	0.	0.	0.	0.	0.
	D		0.	0.	0.	0.	0.
SETOVER	U	AUX.	0.	0.	0.	0.	0.
	D		0.	0.	0.	0.	0.
MULTIPLE	U	MAIN	8.5	5.1	23.4	6.1	6.7
	D		12.5	4.1	22.5	6.0	6.1
MULTIPLE	U	AUX.	4.7	4.6	15.7	3.1	1.8
	D		10.7	3.4	16.3	4.2	3.8
TURNBACK	U	MAIN	0.	0.	12.0	0.	0.
	D		0.	0.	13.0	0.	0.
TURNBACK	U	AUX.	0.	0.	11.0	0.	0.
	D		0.	0.	10.0	0.	0.

Table 31

Tow Size Distribution

L&D 25, Mississippi River

TOW DISTRIBUTION DATA

TOW TYPE NO.	NAME	NO. BRGS PER TOW	DIST. (%)	LOCKAGE TYPE MAIN	LOCKAGE TYPE AUX	BARGES/LOCKAGE MAIN
1	HOPPER JUMBO	2	7	1	1	2.00
		4	7	1	2	4.00
		6	12	1	2	6.00
		8	8	44	3	8.00
		10	12	2	4	5.00
		12	23	2	4	6.00
		15	31	2	5	7.50
2	PETROL JUMBO	1	0	1	1	1.00
		2	5	1	1	2.00
		3	30	1	1	3.00
		4	30	1	2	4.00
		5	5	1	2	5.00
		6	20	1	2	6.00
		8	0	44	3	8.00
		10	10	2	4	5.00
3	PETROL TANKM	1	3	1	1	1.00
		2	17	1	44	2.00
		3	15	44	2	3.00
		4	34	1	2	4.00
		5	15	2	3	2.50
		6	5	2	3	3.00
		7	0	2	4	3.50
		8	3	2	4	4.00
		9	6	3	5	3.00
		10	2	3	5	3.33
4	PETROL TANKL	1	2	1	1	1.00
		2	32	1	44	2.00
		3	7	44	2	3.00
		4	45	2	3	2.00
		5	5	2	3	2.50
		6	7	2	4	3.00
		7	2	2	4	3.50
5	CHEM JUMBO	1	5	1	1	1.00
		2	53	1	1	2.00
		3	10	1	1	3.00
		4	21	1	2	4.00
		5	11	1	2	5.00
6	CHEM TANK M	1	2	1	1	1.00
		2	15	1	44	2.00
		3	40	44	2	3.00
		4	25	1	2	4.00
		5	10	2	3	2.50
		6	3	2	3	3.00
		7	5	2	4	3.50
7	CHEM TANK L	1	0	1	1	1.00
		2	35	1	44	2.00
		3	50	44	2	3.00
		4	5	2	3	2.00
		5	5	2	3	2.50
		6	5	2	4	3.00

Table 32

L&D 26 Capacity Analysis

Annual (1976) Fleet Annual (1976) Tonnage

Tow Selection Policy	Tow Processing Policy	Tonnage (10^6) Existing 600;360 Present Site	Existing 600;360 Present Site	Single 600 Present Site	Single 1200 New Site	Dual 1200;600 Present Site	Tows Existing 600;360 Present Site	Existing 600;360 Present Site	Single 600' Present Site	Single 1200 New Site	Dual 1200;600 Present Site
		*	**			*	*	**			*
FIFO	Standard	54.26	55.64	34.50	96.16	126.25	10,144	9,026	4,742	9,879	17,917
	Ind. Choice	61.85	64.27	39.04			11,432	10,302	5,366		
	RTS	75.06	80.19	44.33			14,464	13,542	6,094		
4U4D	Standard	56.23	57.71	35.95	98.68	129.94	10,434	9,283	4,941	10,138	18,487
	Ind. Choice	64.88	67.58	41.09			11,913	10,752	5,648		
	RTS	76.19	81.26	45.18			14,654	13,705	6,210		
12U12D	Standard	57.64	59.19	36.94	100.57	132.50	10,640	9,470	5,078	10,332	18,890
	Ind. Choice	67.13	70.02	42.59			12,263	10,076	5,853		
	RTS	76.99	81.96	45.73			14,777	13,800	6,293		

* Free Choice in the use of the auxiliary chamber was calculated using a fifty-fifty split in the allocation between the main and auxiliary chambers of those tows that might reasonably have chosen either chamber based on the lockage type required.

** Forced Use in the use of the auxiliary chamber was calculated with all tows that reasonably could using the auxiliary chamber.

characteristics were assumed to be the same as those of L&D 26. Barge loads, dedication factors, and distribution of tonnage among barge types was assumed to be the same as those of L&D 26, also.

94. Lock availability data were derived from the PMS data in the same manner as for L&D 26. The time reduction for noncommercial lockages at L&D 25 was determined in the same manner as for L&D 26; however, since there is only one chamber this value is applied to that chamber. An average of 124 lockages taking 14.31 min to process is experienced during an average month in the shipping season at L&D 25. Since the L&D 27 chambers are so large, no reduction for noncommercial lockages was made, since all of these vessels would probably be able to find room to lock with the commercial tows.

95. L&D 25 was found to be unavailable for lockages an average of 1.2 percent of the time. L&D 27 was found to be unavailable less than 1 percent of the time.

Computed Capacities

96. Using the information derived from the 1976 data, the computation method for determining lock capacities was used to calculate the capacity of L&D 26 under a range of combinations of fleet, commodity mix, and lock operating policies. Capacities were calculated for the present existing locks, for a single 600-ft lock chamber (to determine the impact of not being able to use the auxiliary chamber), a single 1200-ft lock chamber (the proposed replacement project), and dual lock chambers of 1200 ft and 600 ft in length. The results of these calculations are presented in Tables 32-35.

97. Capacities and the number of tows expected, based on the average tow size and tonnage carried through each chamber, were computed for combinations of the following conditions. Lock operating policies included tow selection procedures of FIFO, 4U-4D, and 12U-12D to represent a long series of consecutive lockages. Tow processing policies included the standard policies in which tow reconfiguration in the lock chamber is allowed, IC in which tows may break down in the lock

Table 33

L&D 26 Capacity Analysis

May Fleet Annual (1976) Tonnage

Tow Selection Policy	Tow Processing Policy	Tonnage (10^6) Existing 600;360 Present Site *	Existing 600;360 Present Site **	Single 600 Present Site	Single 1200 New Site	Dual 1200;600 Present Site *	Tows Existing 600;360 Present Site *	Existing 600;360 Present Site **	Single 600' Present Site	Single 1200 New Site	Dual 1200;600 Present Site *
FIFO	Standard	52.92	54.98	34.67	94.64	130.13	9,130	8,105	4,586	9,885	16,967
	Ind. Choice	60.58	63.77	39.46			10,315	9,290	5,219		
	RTS	74.56	80.68	45.11			13,433	12,660	5,965		17,245
4U4D	Standard	54.90	57.09	36.14	97.22	133.92	9,399	8,345	4,779	10,155	17,519
	Ind. Choice	63.65	67.08	41.53			10,760	9,694	5,492		
	RTS	75.68	81.73	45.96			13,607	12,801	6,079		18,287
12U12D	Standard	56.29	58.59	37.19	98.98	136.55	9,583	8,519	4,919	10,338	17,902
	Ind. Choice	65.84	69.48	43.09			11,073	9,986	5,699		
	RTS	76.43	82.46	46.57			13,718	12,896	6,159		18,625

* Free Choice in the use of the auxiliary chamber was calculated using a fifty-fifty split in the allocation between the main and auxiliary chambers of those tows that might reasonably have chosen either chamber based on the lockage type required.

** Forced Use in the use of the auxiliary chamber was calculated with all tows that reasonably could using the auxiliary chamber.

Table 34

L&D 26 Capacity Analysis

Annual (1976) Fleet May 1976 Tonnage

		Tonnage (10^6)					Tows				
Tow Selection Policy	Tow Processing Policy	Existing 600;360 Present Site	Existing 600;360 Present Site	Single 600 Present Site	Single 1200 New Site	Dual 1200;600 Present Site	Existing 600;360 Present Site	Existing 600;360 Present Site	Single 600' Present Site	Single 1200 New Site	Dual 1200;600 Present Site
		*	**			*	*	**			*
FIFO	Standard	60.39	61.54	38.35	106.68	139.53	10,342	9,232	4,733	9,872	18,203
	Ind. Choice	68.78	71.05	43.40			11,654	10,543	5,356		
	RTS	83.17	88.31	49.28			14,629	13,729	6,082		
4U4D	Standard	62.51	63.83	39.90	109.47	143.60	10,627	9,493	4,924	10,131	18,779
	Ind. Choice	72.14	74.71	45.67			12,145	11,003	5,637		
	RTS	84.48	89.53	50.28			14,828	13,892	6,205		
12U12D	Standard	64.05	65.44	41.06	111.45	146.39	10,834	9,679	5,068	10,314	19,176
	Ind. Choice	74.59	77.41	47.34			12,499	11,337	5,842		
	RTS	85.30	90.33	50.94			14,945	13,994	6,287		

* Free Choice in the use of the auxiliary chamber was calculated using a fifty-fifty split in the allocation between the main and auxiliary chambers of those tows that might reasonably have chosen either chamber based on the lockage type required.

** Forced Use in the use of the auxiliary chamber was calculated with all tows that reasonably could using the auxiliary chamber.

Table 35

L&D 26 Capacity Analysis

May Fleet May 1976 Tonnage

		Tonnage (10^6)					Tows				
Tow Selection Policy	Tow Processing Policy	Existing 600;360 Present Site	Existing 600;360 Present Site	Single 600 Present Site	Single 1200 New Site	Dual 1200;600 Present Site	Existing 600;360 Present Site	Existing 600;360 Present Site	Single 600' Present Site	Single 1200 New Site	Dual 1200;600 Present Site
		*	**			*	*	**			*
FIFO	Standard	57.49	59.96	37.76	104.18	142.12	8,996	8,011	4,570	9,833	16,836
	Ind. Choice	65.82	69.46	42.97			10,166	9,177	5,201		
	RTS	81.21	88.09	49.17			13,283	12,547	5,952		
4U4D	Standard	59.63	62.19	39.35	107.03	146.30	9,258	8,244	4,763	10,153	17,410
	Ind. Choice	69.14	73.08	45.22			10,601	9,578	5,474		
	RTS	82.43	89.23	50.11			13,455	12,687	6,065		
12U12D	Standard	61.17	63.81	40.45	108.96	149.17	9,446	8,411	4,896	10,336	17,791
	Ind. Choice	71.59	75.74	46.92			10,920	9,868	5,680		
	RTS	83.18	90.02	50.71			13,560	12,777	6,138		

* Free Choice in the use of the auxiliary chamber was calculated using a fifty-fifty split in the allocation between the main and auxiliary chambers of those tows that might reasonably have chosen either chamber based on the lockage type required.

** Forced Use in the use of the auxiliary chamber was calculated with all tows that reasonably could using the auxiliary chamber.

chamber but must re-form clear of the lock, and the RTS procedure in which tows must arrive at the lock in a configuration that will allow lockage in a single chambering. Both annual 1976 and May 1976 tonnage mixes were tested with both average annual (March) 1976 and May 1976 fleet characteristics.

98. The effects of tows selecting either the main or auxiliary chamber were tested for two separate cases. In general, tows that could single lock in the auxiliary chamber were considered to always select that chamber. All tows that were singles or setover lockages in the main and doubles or setovers in the auxiliary chamber (triples were also included for tank type tows) were considered to have a choice of chambers. In one case, it was considered that the tows would be evenly split in this choice of chamber; in the second case, all tows that had a choice were considered to select the auxiliary chamber. All larger tows were considered to always use the main chamber.

99. One may observe that the improvement in lock capacity in going from the IC to the RTS processing policy is very significant, up to nearly 15 million tons. However, the improvement in going from 4 to 12 in the sequential policy is relatively small. This can be very important since it is readily apparent that the best lock operating policy in all conditions is a combination of the 12U-12D tow selection policy and the RTS tow processing procedure.

100. One should be cautious in quickly accepting that a long sequential series of lockages is the best tow selection policy. Experience in simulation modeling has demonstrated that while the lock utilization may improve under this policy (i.e., less time is required to process the average tow), there has always been a more rapid growth in the average queue length and waiting time associated with these policies than with the FIFO. Since no queuing considerations are accounted for in the lock capacity computation method used in this study, one should carefully analyze these effects before accepting these results.

101. There appears to be little difference in most cases (less than 2 million tons) in the capacity determined when one compares the annual average and the peak month fleet characteristics. The effect is

larger with the 1200-ft chambers but is in the opposite direction. However, when the effects of using the peak month's tonnage mix are compared with the annual tonnage mix, one observes significant increases in the computed capacities. Thus, the particular commodity mix so affects the required empty barge movements, the mix of equipment and, hence, the size of tows that the lockage type mix and the tons carried in each lockage change significantly. This carries very important implications for the necessity to provide very accurate commodity projections and to analyze significant seasonal patterns in commodity mixes, if any exist. Unfortunately, projecting commodity movements is not an exact science.

102. The annual tonnage mix is considered to be the more valid basis for determining the lock capacity values. Additionally, it is acknowledged that the standard tow processing policy is not the most effective policy and that the IC procedure is a workable policy. Based on these observations, the lock capacity for the present locks appears to lie somewhere between 60.6 to 81.7 million tons per year.

Simulation Results

103. In order to confirm the results obtained using the lock capacity computation procedure, several sets of simulation model runs were made with the TOWGEN and WATSIM IV models that were used in the DM11 study. Descriptions of these models are contained in the Attachment to Appendix G of DM11 and will not be repeated here. The new 1976 data used in the computation procedure were used in the simulation model runs. The future tonnage levels were projected with a constant ratio between commodity types until full utilization of the locks was obtained and very large queue levels were reached. A graph of tonnage versus lock utilization was created using the simulation results. From this graph, the tonnage level was obtained that corresponded to the utilization percentage available after adjusting for unavailable time due to maintenance, weather, accidents, and lockages of vessels other than tows. The same correction factors were used as in the computation procedure.

104. Results of the capacity determinations based on earlier

simulation runs reported in DM11, as well as those runs completed as a part of this study, are presented in Table 36. Based on these results, one must conclude that the 1976 commodity mix, fleet characteristics, and lockage times must have created enough of a difference in the total lock processing characteristics to result in the ability to process more tonnage than those based on the available 1972 data. The most significant difference in the 1976 and 1972 data was in the commodity mix and the corresponding shift to large (15 barge) Jumbo hopper tows in the movement of grain shipments.

105. Results of the simulation runs indicate that capacity level of 82 to 83 million tons based on the 1976 data is in agreement with the computation methods. However, the simulations indicate that the FIFO/RTS lock operating policy results in a much higher capacity than is indicated by the computation procedure. No explanation can be given for this difference at this time.

106. There is a difference in the estimated tows locked at this tonnage level of about 2000 tows/year. This is a difference of about 15 percent and is probably due to the differences in the manner in which the tows are placed in the chambers of a dual chamber lock. The computation procedure assigns a portion of the fleet (generally the smaller tows) to the auxiliary chamber and the remaining tows to the main chamber. This assignment remains fixed as the lock traffic increases to the full utilization of the lock. As the auxiliary lock usually has more room for growth, the capacity level is reached with a proportionately larger growth of small tows, i.e., more tows are required to carry each unit of tonnage. The simulation model, however, operates with a fixed fleet and assigns more and more large tows to the auxiliary chamber as the main chamber becomes more fully utilized. Thus, the auxiliary chamber's growth involves increasingly larger tows and, therefore, requires fewer tows to move the capacity level tonnage. It is felt that the estimate of tows determined by the simulation model is more accurate.

107. The capacity determined for the single 1200-ft replacement lock agrees well with that determined by the computation method. The

Table 36

L&D 26 CAPACITY ANALYSIS
Simulation Results

		Tonnage (10^6)						Tows					
Tow Selection Policy	Tow Processing Policy	Existing 600;360 Present Site	Existing 600;360 Present Site	Existing 600;360 Present Site	Single 1200 New Site	Single 1200 New Site	Single 1200 New Site	Existing 600;360 Present Site	Existing 600;360 Present Site	Existing 600;360 Present Site	Single 1200 New Site	Single 1200 New Site	Single 1200 New Site
		'72 Fleet	Large Flt	1976 Flt	'72 Fleet	Large Flt	1976 Flt	'72 Fleet	Large Flt	1976 Flt	'72 Fleet	Large Flt	1976 Flt
FIFO	Standard	58.1			85.7	111.4	98.9	9,796			15,036	11,812	12,803
	Ind. Choice												
	RTS	73.0	78.8	82.8				12,537	9,544	11,446			
12U12D	Standard						98.4						12,781
	Ind. Choice												
	RTS			83.5						11,843			

computation method varies from 96 to 100 million tons and the simulation results indicate a capacity in the range of 98 to 99 million tons. The tow estimate computed by the calculation procedure is not representative since an artificial tow size distribution was used to simulate a multi-vessel environment.

Capacities of L&D 25 and 27

108. Based on the 1976 data available, the capacities of L&D 25 and 27 were computed using the lock capacity computation procedure. Results of these computations are shown below:

Tow Selection Policy	Tow Processing Policy	L&D 25	L&D 27
FIFO	Standard	37.79	160.75
	RTS	44.32	

PART VI: SUMMARY AND CONCLUSIONS

109. This analysis of the capacity of L&D 26 and the adjacent locks resulted from questions raised about earlier capacity determinations made by the Corps of Engineers. These questions involved the adequacy of commodity projections, the composition of the tows that could be expected to use the locks, the accuracy of the lockage operation times, and whether the Corps considered the most efficient operation of the locks.

110. In order to assist in answering some of these questions, the Corps of Engineers developed an analytical capacity computation technique that is based on the use of readily available data. This technique allows the determination of lock capacities for various combinations of tow fleet characteristics (with the resulting lockage type and tow load relations), lock operating policies, commodity mixes, and lock utilization adjustments for periods when the lock could not be used to service tows. This technique could account for the interaction of the tow sizes, lockage type, lock operating policy, and required service time factors. It further accounts for barge movement balance requirements and the commodity mix/tow size relation so that as the commodity mix changes, the resulting change in the empty barge movement ratio on the lockage type and resulting times are properly accounted for in the capacity computation.

111. This technique has some limitations that must be recognized. First, it does not account for the effects of queuing, which can be an important factor, particularly when considering the economics of the lock service time and the delay costs to tows waiting to be serviced and when comparing the lock operating policies to be used. Second, the technique as it is presently constructed accounts directly for lockages of single vessels, i.e., it is primarily only applicable at locks where the majority of the tows are nearly the size of the locks or are larger than the locks. An external adjustment can be made to the tow size distribution used to describe the tow fleet to account for the possibility of multivessel lockages. The success of this approach was

demonstrated by comparing results obtained in this manner with those for a sophisticated simulation model.

112. Finally, the technique is limited by the requirement to externally define which tows will lock in which chambers when more than one chamber size is involved. Improper assignment of tows to these chambers can result in significant changes in the overall capacity, tow fleet characteristics due to the imbalanced growth of traffic volume in the separate chambers, or in overutilization of the smaller chamber.

113. In order to determine the effect of base data on the determination of the lock capacity, an analysis of the most recent lockage, tow, and commodity movement data was made. Over one year of detailed lockage and tow data were available from the recently implemented, Corps-wide lock PMS data. These PMS data provided the basis for most of the analysis. Differences in these base data and those used in earlier studies were:

- a. A basic shift in the proportion of commodity tonnages moving through the locks had occurred since 1972 such that an overwhelming percentage of the traffic involved grain movements.
- b. This shift in the commodity mix apparently caused a significant increase in the empty barge movements experienced at the locks, thereby reducing the average barge loads.
- c. The average tow size defined in barges per tow and tons per tow has increased while the average tons per barge has decreased since 1972. This apparently has been due to the increased volume of grain movements, thereby causing more barges to be available for movement during a period of time and to the increased horsepower available in the towing fleet.
- d. A definite seasonality effect is involved in the tonnage movements and in the lockage times required at L&D 26 and L&D 25 that must be accounted for in any lock capacity determinations.
- e. The locking times are significantly influenced by the lock operating policies and the monthly averages vary considerably from month to month, primarily due to the small number of occurrences of some lockage events and changing conditions at the lock.
- f. The effective unavailability of L&D 26 due to maintenance,

accidents, and weather remains about 2 percent.

g. The use of the lock for servicing vessels other than commercial tows has increased since 1972.

114. In order to account for these changing conditions and possible changes in lock operating policies, the physical lock capacities were recomputed based on average annual 1976 data and on the peak traffic month data. In addition, a simulation model was also used to substantiate these physical capacities. Results of this recomputation of the physical lock capacity demonstrated that (see Tables 32-35):

a. The shift in commodity mix and traffic characteristics had caused a change in the previously determined lock capacity.

b. The physical lock capacity computation is very sensitive to the lock operating policy used and to the mix of commodities being moved through the locks.

c. Differences between annual and peak month traffic characteristics do not significantly affect the physical capacity determination.

115. The above capacity estimates are subject to the following limitations and observations:

a. The numbers represent the physical capacity of a lock, not its economic or social optimum capacity. In other words, the assumption is that during a major part of the shipping season the demand on the lock exceeds the capability of the lock to process or handle the traffic.

b. The treatment of multiple tow lockages as single tows equal in size to the combined smaller tows and with lockage times equal to the size of the larger tow may understate the actual lockage time associated with the multiple tows. In other words, it may not be realistic to assume that two or more smaller tows in the same lock chamber can lock in the same amount of time as a single large tow. In addition for safety reasons often small tows cannot be mixed in the lock chamber. This primarily affects the 1200-ft chamber capacity estimates.

c. The estimated single locking times may be biased downward by the following:

(1) Average tow sizes of non-RTS single lockage tows are smaller on average than double lockage tows split into RTS configuration.

(2) Towboats of non-RTS single tows are generally larger than RTS helper boats.

(3) Helper boats in RTS tows could often be in a configuration making maneuvering less efficient.

d. The physical capacity estimates assume tow sizes will not change in the future. However, historically tons per tow have increased rather dramatically leading to larger capacities at the existing and proposed new Locks 26 and Locks 27 and smaller capacity estimates at Lock 25. The significant increase in grain traffic relative to the growth in other commodities at Locks 26 no doubt strongly influenced this recent trend to larger tows. Developments in the future could cause further significant changes in lock capacity estimates.

116. There are many interrelated time-varying factors that significantly affect the capacity of a lock to pass commodity tonnage. Several of these factors have changed since the last analysis of the capacity of L&D 26. Unfortunately there is still no firm definition of how a lock's capacity is to be determined since if for no other reason, there is no good way to predict how commodities or tow characteristics will change. Also, there is a lack of knowledge of the factors that influence the makeup of tows; yet this is a very significant factor in the determination of lock capacity.

117. Based on the findings of this study, a serious effort should be made to establish a standard coordinated procedure for computing lock and waterway system capacities that will adequately account for the widely varying conditions throughout the waterway systems under the Corps of Engineers responsibility. Such a procedure should be compatible with those used in determining the capacities of other modes of intercity or interregional freight transportation so that these capacities may be used in intermodal analyses. Separate procedures may be required in comparing transportation modes and in an economic analysis.

118. It is further recommended that the lock capacity computations method developed for this study be improved to internally account for multivessel lockages, to internally allocate tows to lock chambers when multichambers are involved, and to account for queuing effects to the extent possible.

APPENDIX A

LOCK CAPACITY CALCULATIONS - ARITHMETIC METHOD

1. Table A1 presents the commodities shipped through Locks and Dam 26 (L&D 26) during the month of August 1972. August was used because it was a peak month, traditionally averaging about 9-1/2 percent of a year's shipments. Some other month might be the "historically stable" month for a different lock. Table A2 reproduces the 1972 percentage distribution of the type of barges used to transport each of the commodities. For example, 13 percent of all petroleum products were transported using 35- × 195-ft petroleum Jumbo barges.

2. Table A3 converts Tables A1 and A2 to a different format to show the observed average barge load (at L&D 26), and the percentage of dedicated movement that was experienced (dedicated equipment cannot be used to transport a different commodity).

3. Table A4 is constructed using the following arithmetic expression to convert tonnage to loaded barges.

$$\textit{Upbound Hopper J Barges} = \frac{\text{Tonnage Up}}{\text{Average Tons per Tow}} \qquad (1)$$

$$\text{Hopper J Barges} = \frac{1137320}{1314} = 866 \text{ for upbound tows}$$

The total quantity of barges is simply a "balancing" process which assumes in the case of Hopper J barges, for example, that the excess of full barges in one direction will be returned empty. The dedicated equipment percentage (Table A3) is used in obtaining the returns of empty barges.

4. Average tons per barge is obtained using data from Tables A3 and A4 and arithmetic expression (2).

Barges	Average Tons per Barge		Tonnage	
3710	(1314)	=	3 575 394	
144	(1400)	=	100 800	
252	(2460)	=	309 960	
246	(2973)	=	365 679	
578	(1400)	=	404 600	(2)
86	(2460)	=	105 780	
82	(2973)	=	121 893	
5098			4 984 106	

$$\frac{4\ 984\ 106}{5098}(0.968) = 946.37 \text{ tons/barge}$$

The percentage (0.968) is used to reduce average tons per barge as the average barge load found in Table A3 is based on lockmaster records. These tonnages are about 3 to 4 percent higher than those reported to the Waterborne Commerce Statistical Center (WCSC) at New Orleans by the barge companies. The WCSC data is considered to be accurate. The reason for this difference is that lockmasters "round-off" their reports usually to the higher value (with respect to L&D 26).

5. Table A5 is the vehicle used to convert the existing (or assumed) percentage distribution of barges per tow by barge type (column 2 of Table A5) to the average number of barges per tow. By referring to the commodities carried by barge type (Table A2), one knows the commodities included in a particular average tow size. The calculation process for weighted average tow size is as follows (for Hopper J Barge types):

Barges (percent)		
2 (0.21)	= 0.42	$\frac{(0.21)(3710)}{7.54} = 103$
4 (0.13)	= 0.52	
6 (0.17)	= 1.02	
8 (0.11)	= 0.88	(3)
10 (0.11)	= 1.10	and $\frac{3710}{7.54} = 492$
12 (0.15)	= 1.80	
15 (0.12)	= 1.80	
	7.54	

6. The Tow Fleet percent distribution column of Table A6 can be viewed two ways. First, simply as a percentage distribution; secondly, and more importantly, as saying that 60.7 tows of each 100 tows passing through the lock will be composed of Hopper J barges. Viewed in this context (called normalizing of data) the quantity of actual tows passing through the lock is immaterial. No matter what the quantity, 60.7 of 100 tows will consist of Hopper J barges. It can be expected that (on the average) the 60.7 of 100 Hopper J barge tows will be observed so long as (a) the percentage distribution of commodities remains as

displayed in Table A1; (b) the data of Table A2 do not change; (c) the tonnage upstream and downstream distribution is stable (Table A3); and (d) the distribution of tow sizes remains constant (Table A5).

7. Table A7 displays the process resulting in barges per tow, and tows per lockage. There are two sets of data based upon judgment. Both sets are critical to the estimate of lock capacity.

8. The first concerns the number of cuts by lockage type. Using Hopper J barges as an example, a two-barge tow would require one cut (lockage) to pass through either the main or the auxiliary chamber. A four-barge tow would require two cuts to pass through the auxiliary chamber. One setover (indicated by the 44) would pass eight barges through the main chamber in a single lockage. Eight barges would require three cuts in the auxiliary chamber. The amount of discretion that can be used by the analyst in his choice of values is limited by both the lock dimensions, and observed practices at the lock. The type of lockage required for most tow sizes is straightforward. However, some tow sizes can be structured in either single or setover configurations. Observation of tow size and lockage types guides the lockage type selected in these tows.

9. The second area of judgment is the assumed distribution of the chamber fleet between the main and auxiliary chamber. Changes in the distribution of type of lockage (column 3), and/or in the distribution of the number of tows by chamber (column 4) results in changes in the weighted average lockage time per tow (of Table A11) and thus to the estimated lock capacity (of Table A13). Obviously the weighted average tow sizes of Table A7 also change based upon the values assumed "Lockage type of cuts" and the "assumed number of tows by chamber."

10. Table A7 uses the "Normalization" idea to develop average barges per lockage. The 60.7 Hopper J type tows are distributed into barges per tow by the following process:

$$(0.21)\ (60.7) = 12.7$$

$$(0.13)\ (60.7) = 7.9 \qquad (4)$$

where the 0.21 and 0.13 are the 1972 observed percentage distribution of barges per tow at L&D 26. Column 2 of Table A7 then states that of every 100 tows passing through L&D 26, 12.7 tows would consist of two Hopper J barges - given there are no data changes in Table A7. It is noted that this tow can be passed through the lock in a single lockage. It is expected one half of the 7.9 tows per 100 will be locked through the main and auxiliary chambers when the locks are operating at capacity (or 3.95 tows in each of the locks). Since this is a single lockage tow, the 3.95 lockages would be necessary to pass 3.95 tows. Utilization of the auxiliary lock involves two cuts, or 7.9 lockages, for 3.45 tows. This would involve 15.8 barges total (3.95 × 4). Going to the 8 barge tows, 6.7 tows would be expected (of every 100 tows), and these could be locked through the main chamber in the setover configuration (represented by the 44 in column 3). One lockage would be required. A 10 barge tow would require double locking in the main chamber, and four lockages (cuts) if the auxiliary chamber were used (column 7).

11. The average barges per lockage for Hopper J type tows is obtained as follows:

$$\frac{\text{Total Barges}}{\text{Number of Lockages}} = \begin{matrix}\text{Average Barges} \\ \text{per Lockage}\end{matrix} \tag{5}$$

$$\frac{386.3}{62.05} = 6.23$$

12. The purpose of Table A8 is construction of average lock times for the various types of lockages established from the assumption of lockage procedures. The Lock Component Times/Tow are established by direct measurement at the locks. Data are collected over many months. There is really a range of values for each of the different operations (Single, Setover). The range of values are evaluated to establish the average of 24 min for single lockages in the main chamber, and 15 min for the auxiliary chamber.

13. Tables A9 and A10 are simply summaries developed from the details in Table A7. Referring to column 3 of Table A7 (main chamber)

it is noted that there are 3.95 plus 5.2 tows which utilize single lockages in transporting Hopper J barges through L&D 26. The total for single lockages for all tow types in the main chamber is (from column 4, Table A7):

$$\begin{array}{r} 3.95 \\ 5.20 \\ 0.10 \\ 0.20 \\ 0.45 \\ 0.95 \\ 1.50 \\ \underline{0.20} \\ 12.55 \end{array} \tag{6}$$

14. Table A11 is constructed simply by multiplying the quantity of single locked tows (12.55) by the time required to perform a complete single lockage (46.25), summing the total (5197.51), and dividing by the total number of lockages (86.55) to obtain the average minutes per lockage (60.05) for the main chamber when operating the locks under FIFO policy.

15. Table A12 constructs the quantity of lockages that could be performed in a typical month. The amount of downtime (2 percent) is deducted from the total available minutes. Also deducted are 5 lockages in the main chamber and 5 in the auxiliary utilized by recreational craft and/or lightboats.

16. Table A13 simply multiplies lockages per month, barges per lockage, and tons per barge to obtain the lock capacity for a single month. The product is divided by 9.5 percent because August traditionally produces 9.5 percent the tonnage at L&D 26. The tonnage figures of Table A1 are 9.5 percent of the total tonnage for the year. The end result is the annual tonnage at each lock (50.421 million tons) for the main chamber, and (22.265 million tons) for the auxiliary chamber. Total tonnage is thus 72.690 million annually. This estimate compares with the 73.0 million tons estimated using WATSIM-TOWGEN, or a difference of 0.43 percent.

17. The calculation process depicted in this paper has been

programmed for computer application. The computer program is considered to be in "first draft" form. This program does not follow the exact sequence of calculations depicted in this paper and will ultimately be programmed in the form resulting in the most cost efficient computation process. The exact solution may differ from the sequence presented in this paper. The computer program can produce slightly different values than this paper (for the same assumption) due to differences in "rounding-off" the individual values computed during the process.

Table A1

Commodity Matrix (Monthly) Tonnage

Name	No.	Up	Down	Total
(1)	(2)	(3)	(4)	(5)
Corn	1	158	1,426,168	1,426,326
Soybeans	2	277	450,896	451,173
Grain	3	923	238,982	239,905
Coal	4	757,205	254	757,459
Petroleum	5	719,185	55,101	774,286
GSSA	6	32,153	82,500	114,653
Fe + Steel	7	77,914	104,848	182,762
Ind Chem	8	344,985	32,825	377,810
Agr Chem	9	240,385	13,788	254,173
Oth + Misc	10	268,690	133,787	402,477
Total		2,441,875	2,539,149	4,981,024

Table A2

Commodity Distribution by Barge Type (%)

Commodity No.	Hopper J. 35 × 195 ft	Petrol J. 35 × 195 ft	P TANKM 50 × 240 ft	P TANKL 50 × 290 ft	Chem J. 35 × 195 ft	C TANKM 50 × 240 ft	C TANKL 50 × 240 ft
1	100						
2	100						
3	100						
4	100						
5		13	40	47			
6	100						
7	100						
8					40	28	32
9					100		
10	100						

Table A3

Tonnage Distribution by Barge Type

Barge Type	Tonnage by Barge Type Up	Tonnage by Barge Type Down	Average Barge Load tons	Dedicated Equipment %
Hopper J	1,137,320	2,437,435	1,314	0
Petrol J	93,494	7,163	1,400	100
P TANKM	287,674	22,040	2,460	100
P TANKL	338,017	25,897	2,973	100
Chem J	378,379	26,918	1,400	100
C TANKM	96,596	9,191	2,460	100
C TANKL	110,395	10,504	2,973	100
Total	2,441,875	2,539,148		

Table A4

Summary of Barge Distribution

Barge Type	Barge Fleet Loaded Up	Barge Fleet Loaded Down	Barge Fleet Empty Up	Barge Fleet Empty Down	Up	Down	Total
Hopper J	866	1855	989	0	1855	1855	3710
Petrol J	67	5	5	67	72	72	144
P TANKM	117	9	9	117	126	126	252
P TANKL	114	9	9	114	123	123	246
Chem J	270	19	19	270	289	289	578
C TANKM	39	4	4	39	43	43	86
C TANKL	37	4	4	37	41	41	82
	1510	1905	1039	644	2549	2549	5098
Total	3415		1683		5098		

Table A5

Calculated Barges per Tow

Tow Fleet Distribution							
Type	Barges per Tow	% Barges/ Tow	No. of Tows	Type	Barges per Tow	% Barges/ Tow	No. of Tows
Hopper J	2	21	103	P TANKL	1	6	5
	4	13	64		2	24	19
	6	17	84		3	24	19
	8	11	54		4	43	34
	10	11	54		7	3	2
	12	15	74			3.19*	79
	15	12	59	Chem J	1	5	4
		7.54*	492		2	13	11
Petrol J	1	32	10		3	9	8
	2	5	2		6	27	24
	3	10	3		8	27	24
	4	5	2		10	9	8
	5	10	3		12	5	4
	6	23	7		14	5	4
	12	10	3			6.56*	87
	14	5	2	C TANKM	1	9	3
		4.70*	32		2	27	8
P TANKM	1	2	1		3	37	10
	2	26	17		4	9	3
	3	23	15		5	9	3
	4	23	15		6	9	3
	5	8	5			3.09*	30
	6	8	5	C TANKL	2	25	7
	7	5	3		3	58	16
	10	5	3		4	17	5
		3.88*	64			2.92*	28

* Weighted average tow size.

Table A6

Summary of Fleet Characteristics

Type	Barge Fleet Total Up	Barge Fleet Total Down	Barge Fleet #	Barge Fleet %	Average Tow Size (Bgs/Tow)	Tow Fleet Distribution Total Up	Tow Fleet Distribution Total Down	Tow Fleet Distribution Total #	Tow Fleet Distribution Total %
Hopper J	1855	1855	3710	72.8	7.54	246	246	492	60.7
Petrol J	72	72	144	2.9	4.70	15	15	30	3.7
P TANKM	126	126	252	4.9	3.88	33	33	66	8.1
P TANKL	123	123	246	4.8	3.19	39	39	78	9.6
Chem J	289	289	578	11.3	6.56	44	44	88	10.9
C TANKM	43	43	86	1.7	3.09	14	14	28	3.5
C TANKL	41	41	82	1.6	2.92	14	14	28	3.5
	2549	2549	5090	100.0					
Total	5098					405	405	810	100.0

Table A7

Weighted Average Barges per Lockage by Barge Type and Chamber

			Main Chamber					Auxiliary Chamber				
Tow Type	Number of Barges Tow	Percent of Tows	Lockage Type	Number Tows	Number Lockage	Number Barges	Average Barges per Lock	Lock Type	Number Tows	Number Lockage	Number Barges	Average Barges per Lockage
Hopper J	2	12.7	1	—	—	—		1	12.7	12.7	25.40	
	4	7.9	1	3.95	3.95	15.80		2	3.95	7.9	15.80	
	6	10.4	1	5.2	5.2	31.20		2	5.2	10.4	31.20	
	8	6.7	44	6.7	6.7	53.60		3	—	—	—	
	10	6.7	2	6.7	13.4	67.00		4	—	—	—	
	12	9.1	2	9.1	18.2	109.20		4	—	—	—	
	15	7.3	2	7.3	14.6	109.50		5	—	—	—	
		60.7		38.95	62.05	386.30	6.23		21.85	31.0	72.40	2.34
Petro J	1	1.2	1	—	—	—		1	1.2	1.2	1.20	
	2	0.2	1	—	—	—		1	0.2	0.2	0.40	
	3	0.4	1	—	—	—		1	0.4	0.4	1.20	
	4	0.2	1	0.1	0.1	0.40		2	0.1	0.2	0.40	
	5	0.4	1	0.2	0.2	1.00		2	0.2	0.4	1.00	
	6	0.9	1	0.45	0.45	2.70		2	0.45	0.9	2.70	
	12	0.4	2	0.4	0.8	4.80		4	—	—	—	
	14	0.2	2	0.2	0.4	2.80		5	—	—	—	
		4.0		1.35	1.95	11.70	6.00		2.55	3.30	6.90	2.09
P TANKM	1	0.1	1	—	—	—		1	0.1	0.1	0.10	
	2	2.1	1	—	—	—		44	2.1	2.1	4.20	
	3	1.9	44	0.95	0.95	2.85		2	0.95	1.9	2.85	
	4	1.9	1	0.95	0.95	3.80		2	0.95	1.9	3.80	
	5	0.6	2	0.3	0.6	1.50		3	0.3	0.9	1.50	
	6	0.6	2	0.3	0.6	1.80		3	0.3	0.9	1.80	
	7	0.4	2	0.4	0.8	2.80		4	—	—	—	
	10	0.4	3	0.4	1.2	4.00		5	—	—	—	
		7.9		3.3	5.1	16.75	3.28		4.70	7.80	14.25	1.83
P TANKL	1	0.6	1	—	—	—		1	0.6	0.6	0.60	
	2	2.3	1	—	—	—		44	2.3	2.3	4.60	
	3	2.3	44	1.15	1.15	3.45		2	1.15	2.3	3.45	
	4	4.2	2	2.1	4.2	8.40		3	2.1	6.3	8.40	
	7	0.2	2	0.2	0.4	1.40		4	—	—	—	
		9.8		3.45	5.75	13.25	2.30		6.15	11.50	17.05	1.48
Chem J	1	0.5	1	—	—	—		1	0.5	0.5	0.5	
	2	1.4	1	—	—	—		1	1.4	1.4	2.8	
	3	1.0	1	—	—	—		1	1.0	1.0	3.0	
	6	3.0	1	1.5	1.5	9.00		2	1.5	3.0	9.0	
	8	3.0	44	3.0	3.0	24.00		3	—	—	—	
	10	1.0	2	1.0	2.0	10.00		4	—	—	—	
	12	0.5	2	0.5	1.0	6.00		4	—	—	—	
	14	0.5	2	0.5	1.0	7.00		5	—	—	—	
		10.7		6.50	8.5	56.00	6.59		4.40	5.90	15.30	2.59
C TANKM	1	0.4	1	—	—	—		1	0.4	0.4	0.40	
	2	1.0	1	—	—	—		44	1.0	1.0	2.00	
	3	1.2	44	0.6	0.6	1.80		2	0.6	1.2	1.80	
	4	0.4	1	0.2	0.2	0.80		2	0.2	0.4	0.80	
	5	0.4	2	0.2	0.4	1.00		3	0.2	0.6	1.00	
	6	0.4	2	0.2	0.4	1.20		3	0.2	0.6	1.20	
		3.7		1.2	1.6	4.80	3.00		2.6	4.20	7.20	1.71
C TANKL	2	0.9	1	—	—	—		44	0.9	0.9	1.80	
	3	2.0	44	1.0	1.0	3.0		2	1.0	2.0	3.00	
	4	0.6	2	0.3	0.6	1.2		3	0.3	0.9	1.20	
		3.5		1.3	1.6	4.2	2.63		2.2	3.80	6.00	1.58
				56.05	86.85	493.00	5.70		44.45	67.50	139.10	2.06

1.84 $\frac{\text{Lockages}}{\text{Tows}}$ 8.80 $\frac{\text{Barges}}{\text{Tow}}$ 11.52 $\frac{\text{Lockages}}{\text{Tow}}$

3.13 $\frac{\text{Barges}}{\text{Tow}}$

Table A8

Lock Time Requirements

	Lock Component Times/Tow Main	Lock Component Times/Tow Aux
Chamber Time		
Single	24	15
Setover	46	62
Double	100	70.5
Triple	157	123
Exchange Ent.	20.5	18.5
Turnback Ent.	3	3
Exchange Exit	8	8
Turnback Exit	13	13

Ready to Serve (RTS)

Double = 2(single) + 1(turnback exit) + 1(turn ent.)

Triple = 3(single) + 2(turnback exit) + 2(turn ent.)

	Main	Aux
Double RTS	64.0	46.0
Triple RTS	104.0	77.0

First in First Out (FIFO)

	Main	Aux
Exchange Ent. + Exit	28.5	26.5
Turnback Ent. + Exit	16.0	16.0
TOTAL	44.5	42.5
AVG	22.25	21.25

Lockage Type	FIFO Locking Time per Tow Main	FIFO Locking Time per Tow Aux	Locking Time per Tow Ready to Serve Main	Locking Time per Tow Ready to Serve Aux
Single	46.25	36.25	46.25	36.25
Setover	68.25	83.25	68.25	83.25
Double	122.25	91.75	86.25	67.25
Triple	179.25	144.25	126.25	98.25

Table A9

Number of Tows by Lockage Type

	Main		Auxiliary	
	Number	Percent	Number	Percent
S	12.55	22	18.50	42
St	13.40	24	6.30	14
D	29.70	53	16.25	37
T	0.40	1	3.40	8
Total	56.05		44.45	

Table A10

Number of Lockages by Lockage Type

	Main		Auxiliary	
	Number	Percent	Number	Percent
S	12.55	15	18.50	27
St	13.40	15	6.30	9
D	59.40	69	32.50	48
T	1.20	1	10.20	15
Total	86.55		67.50	

Table A11

WTD. Lockage Time

	FIFO		RTS	
	Main	Auxiliary	Main	Auxiliary
S	580.44	670.63	580.44	670.63
St	914.55	524.48	914.55	524.48
D	3630.83	1490.94	2561.63	1092.81
T	71.70	490.45	50.10	334.05
Total	5197.51	3176.49	4106.71	2621.96
Min./ Lockage	60.05	47.06	47.45	38.84

Table A12

Calculation of Lock Cycles per Month

(Ready to Serve)

Main	Auxiliary
No. of Lockages = $\frac{(30)\ (24)\ (60)\ (0.98)}{47.45} = 893$	$\frac{(30)\ (24)\ (60)\ (0.98)}{38.84} = 1090$
Less 5 lightboat lockages = 888	= 1085
Computed tow size = 8.8 8.80 (945.79) = 8323 tons per tow	$\frac{800{,}000\ (0.095)}{8323}$ = 9.1 or 10 total lightboat lockages*

* The St. Louis District estimated that 800,000 tons of commodities would be unable to transmit L&D 26 due to lightboat lockages. This calculation is necessary to convert 800,000 tons to its equivalent number of lockages.

Table A13

Estimated Locks Capacity

	Main	Auxiliary
Lockages/month	888.0	1085.0
Barges/lockage	5.7	2.06
Tons/barge	946.37	946.37
Month's capacity (millions of tons)	4.790	2.115
Annual capacity	50.421	22.265
Annual capacity	72.690 million tons	

APPENDIX B

DIFFERENCES BETWEEN PMM&C DATA AS REPORTED AND AS USED IN SIMULATION STUDIES

Adjustments to Data for Capacity Analysis by PMM&C

1. PMM&C only reported weighted average approach and exit times, the weighting being based on the distribution of the types of approaches and exits. No record could be found in their report that presented the distribution of times nor the average times for each type of approach and exit. Thus, it is quite likely that the average times are weighted by a different ratio of approach and exit types than the distributions used in deriving the approach and exit times for the simulation modeling and computation technique.

Differences in Definitions and Use of Data by PMM&C and Corps

2. There are basically five major factors that would cause one to observe differences in the lockage times reported by the Corps and by PMM&C even though both claim to use the same data source. This apparent difference in times is the cause of some concern to many persons due to the significant effect that time can have on the determination of capacity.

3. Probably one of the major causes of differences in Corps and PMM&C times is the fact that the Corps only had two of the six data sets from the test periods available to use in its study. These data were from the first of the Base condition data periods and the Switchboat test period. The other two Base test periods and the Guide Wall Extension and the Industry Choice test periods were not available to the Corps at the time the simulation study was initiated.

4. This fact becomes even more significant when one considers how these data were applied. The Corps used each data set separately to represent the different lock operating procedures. PMM&C combined all of the test data from the six data collection periods to obtain average times for specific lockage components to the extent that this was possible.

5. This difference in the application of the data bases used in the two studies was significant since there was a year's time between

the first Base and the Switchboat test periods used by the Corps and the other test periods. Therefore, there could be and in fact were considerably different operating environments for these test periods. Differences in the conditions that will most affect the average times used in the two studies include: (a) different lifts that the locks must operate between the pools, therefore requiring much different chambering times; (b) different conditions in the approach channels, therefore requiring much different approach, chamber entry, and exit times; (c) different approach and exit type mixes, therefore different weighted average approach and exit times; and finally (d) different mixes of tows in the fleet being processed. The effect of the differences in lift can be observed by considering the average chambering times for single straight lockages, which is primarily a chamber filling or emptying time. These times for the different test periods are:

	Base	Switchboat	Guide Wall	Industry Choice
Up	13.1	11.5	15.2	14.9
Down	12.7	11.1	13.5	12.6

Remembering that the Base condition is a combination of data collected in 1973 and 1974 (the largest portion of the test data) and that the Switchboat test period was in 1973 while the other two test periods were about the same time as the 1974 Base period, the difference of nearly 3.5 min in filling time and 1.5 and 2.4 min in emptying times is a good indication of the potential impact of these conditions alone.

6. The Corps was plagued by the small sample sizes and in some cases lack of data for some lockage component times. This was particularly true in the case of single and setover lockages. The Base test period was particularly lacking enough data, which was one of the reasons that PMMC extended the Base tests. Directionally, the Base condition was so bad that up and down samples were combined with data collected over a longer period by the St. Louis District. This also took into account special conditions at the test period. PMM&C data were compared with the Corps data below:

		Base Period Sample Sizes		
		Singles	Knockouts and Setover Singles	Doubles
PMM&C	Up	14	32 + 29 = 61	77
Corps	Up	9	21	26
PMM&C	Down	6	23 + 2 = 25	117
Corps	Down	4	10	43

7. Another factor that has an impact on the overall average lockage times was the way that the Corps had to define and group the lockage times for use in the simulation model available for the analysis of capacity. First, the basic time definition for the chambering process and the exit was different and therefore required an adjustment of the collected times. The simulated exit process involved only the movement of a tow from the lock gates to the clearance point, whereas the collected exit times included the refleeting of double, setover, and knockout lockages when this took place in the chamber area. Also, only one average exit time was allowed in the simulation model for all lockage types. To ensure that refleeting times would not be included in the exit times, the single straight exit only times were used for all lockage types in the simulation model input data. The chambering times used in the model required the combining of the chamber entry times, the chambering or hardware operating times for all cuts, the turnback, the approach time of the last cut, the exit of the first cut, and the last cut exit time after an appropriate adjustment for the exit time for doubles, setovers and knockouts. The fly and exchange approach times of all lockage types were grouped as required for input to the simulation model. Therefore, there is an implicit lockage mix or effect of tow size distribution built into the approach times. The Corps did not adjust this mixing effect when the simulation runs for larger tow sizes were made; therefore these times are probably understated. Finally, no data were available from PMM&C for the auxiliary chamber at L&D 26. Therefore, the Corps had to base the lockage component times for the auxiliary chamber on data that had been routinely collected by lock personnel. These data were not defined to the same level of detail as were the data collected by PMM&C on the main chamber. PMM&C later

collected some data for the auxiliary lock which was used in an analysis of its capacity.

8. In comparing PMM&C's average time data and the Corps' data used on either the simulation model or the computation procedure, one must keep in mind that PMM&C includes in its average approach and exit times the observed mix of different approach and exit types. The Corps' times involve simulated or theoretical mixes, respectively. The computation procedure eliminates fly approach and exit types.

Differences in PMM&C and the Corps Capacity Estimates

9. There has been a great deal of concern expressed about differences in the estimated capacities derived by PMM&C and the Corps. The differences are primarily the result of differences in the basic assumptions used in arriving at the stated capacity and not in the basic data used. These differences have been thoroughly discussed by the Corps in Attachment 2 to Appendix G, contained in Part II of the Supplemental Economic Data report prepared by the St. Louis District. One of the most significant results of the two independent analyses is that the estimated capacities were as close as they were. Taking into account the differences in the basic assumptions, the St. Louis District demonstrated that the PMM&C and Corps estimated capacities can be resolved to within 2 percent, well within the accuracy of projected traffic growth.

10. It therefore appears futile to be so concerned over differences in the basic data. The primary factors in the differences are the method of handling seasonality, accounting for reporting differences in official tonnage and tonnages recorded at the locks, noncommercial lockages, and interference in the approach channel.

11. Another point to consider, is that the Switchboat capacity used as the basis for replacement is considered too hazardous to be used by industry, particularly in the lower approach. The actually applied operational procedure, Industry Choice, has a lower estimated capacity. PMM&C's estimate is 74.2 compared with the 73 million tons used in the replacement analysis, i.e., a 1.6 percent difference. Adjusted for WCSC tonnage (official) this becomes 71.8.

Table B1

Comparison of PMM&C Processing Times VS Corps Processing Times

L&D 26

Lockage Type	Corps Times						PMM&C**			Percent Difference		
	1U1D	FIFO	3U3D	RTS-FIFO	4U4D	IC*	Base	Switch-Boat	IC	FIFO/Base	RTS FIFO/Switch	IC/IC
Single U	52.5	46.3	44.2	46.3	40.0	40.0	45.5	43.7	42.0	+1.0	+6.9	-4.8
Single D	52.5	46.3	44.2	46.3	40.0	40.0	36.5	37.6	34.4	+26.8	+23.1	+16.3
Double U	125.5	119.3	117.2	86.3	117.2	82.2	121.3	96.0	102.5	-1.6	-10.1	-19.8
Double D	131.5	125.3	123.2	86.3	123.2	82.2	128.6	96.7	101.7	-2.3	-10.8	-19.2
Setover† U	74.5	68.3	66.2	68.3	62.0	62.0	68.1	59.0	59.9	+0.3	+15.8	+3.5
Setover D	74.5	68.3	66.2	68.3	62.0	62.0	56.2	54.0	57.9	+21.5	+26.5	+7.1

* For Industry Choice (IC), all single lockages are assumed to lock last in the lockage sequence of 4 vessels; therefore, these lockage types have a turnback approach/exit in all cases. Doubles are assumed to always have 3U-3D type series for approach/exit types.

** PMM&C processing times after adjustments. (From Table VI.2 p VI-8, Evaluation of Operational Improvements at L&D 26 Mississippi River.)

† Setover lockages include both setover single and knockout single lockage types.

1

Table B2

Average Total Processing Times in Main Channel

L&D 26

Lockage Type	Main Chamber						1972 RTS
				PMM&C			
	May 76	Aug 76	Nov 76	Base	Switch-boat	IC	
Single U	31.1	--	34.2	45.5	43.7	42.0	46.3
Single D	30.9	--	33.9	36.5	37.6	34.4	46.3
Double U	90.9	--	90.4	121.3	96.0	102.5	86.3
Double D	96.0	--	94.3	128.6	96.7	101.7	86.3
Setover U	70.6	--	61.0	73.6	57.2	61.1	68.3
Setover D	61.9	--	60.8	63.2	53.8	55.1	68.3
Knockout U	38.8	--	51.7	62.3	61.0	58.6	68.3
Knockout D	47.9	--	48.0	53.8	54.0	58.9	68.3

APPENDIX C

DETERMINATION OF AVERAGE ANNUAL LOCKAGE COMPONENT TIMES

Table C1

Single Exchange Approach Times

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	14.4	5	72.0	26.0	1	26.0	6.1	25	152.5	11.2	20	224.0
Nov 75	8.0	2	16.0	18.4	5	92.0	9.0	7	63.0	10.7	12	128.4
Dec 75	13.8	5	69.0	16.0	13	208.0	6.0	16	96.0	11.0	8	88.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	19.0	4	76.0	22.3	3	66.9	4.7	6	28.2	6.6	5	33.0
Mar 76	12.5	2	25.0	20.0	9	180.0	11.8	14	165.2	11.3	11	124.3
Apr 76	15.0	1	15.0	7.5	2	15.0	8.8	12	105.6	15.5	12	186.0
May 76	25.0	1	25.0	26.5	2	53.0	9.4	19	178.6	7.8	13	101.4
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	9.8	4	39.2	15.4	7	107.8	7.8	8	62.4	15.6	8	124.8
Aug 76	18.3	8	146.4	17.4	5	87.0	6.3	14	88.2	6.5	17	110.5
Sep 76	15.3	4	61.2	17.0	4	68.0	7.7	15	115.5	8.1	14	113.4
Oct 76	14.7	3	44.1	12.3	6	73.8	7.3	18	131.4	15.2	17	258.4
Nov 76	13.5	6	81.0	14.0	4	56.0	6.6	8	52.8	6.3	8	50.4
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		45	669.9		61	1033.5		162	1239.4		145	1542.6
AVG			14.89			16.94			7.65			10.64

Table C2

Single Turnback Approach Times

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	0	0	--	1.0	1	1.0	2.1	9	18.9	2.1	15	31.5
Nov 75	2.9	7	20.3	1.5	6	9.0	4.8	5	24.0	5.3	7	37.1
Dec 75	2.4	10	24.0	2.0	31	62.0	1.0	1	1.0	2.1	7	14.7
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	1.0	4	4.0	1.8	12	21.6	3.0	7	21.0	2.7	12	32.4
Mar 76	2.1	14	29.4	1.3	9	11.7	7.3	7	51.1	12.6	9	113.4
Apr 76	2.3	6	13.8	1.3	7	9.1	1.0	4	4.0	4.6	10	46.0
May 76	2.8	11	30.8	2.1	11	23.1	5.8	15	87.0	2.8	11	30.8
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	6.6	11	72.6	1.3	23	29.9	4.8	6	28.8	1.5	12	18.0
Aug 76	5.5	22	121.0	1.3	23	29.9	2.4	7	16.8	2.9	15	43.5
Sep 76	1.8	11	19.8	2.1	13	27.3	1.0	9	9.0	1.3	12	15.6
Oct 76	2.1	21	44.1	1.5	29	43.5	2.0	4	8.0	3.2	21	67.2
Nov 76	3.6	22	79.2	1.7	24	40.8	6.3	9	56.7	3.7	6	22.2
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		139	459.0		189	308.9		83	326.3		137	472.4
AVG			3.30			1.63			3.93			3.45

Table C3

Single Chambering Times

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	20.8	5	104.0	18.0	2	36.0	15.9	45	715.5	16.4	57	934.8
Nov 75	20.6	10	206.0	17.5	11	192.5	15.9	21	333.9	15.8	37	584.6
Dec 75	22.1	18	397.8	19.4	49	950.6	15.4	44	677.6	14.7	43	632.1
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	21.3	8	170.4	19.9	17	338.3	16.2	27	437.4	17.0	36	612.0
Mar 76	17.7	20	354.0	18.4	20	368.0	13.2	58	765.6	13.5	63	850.5
Apr 76	16.3	8	130.4	16.5	11	181.5	11.7	27	315.9	12.5	39	487.5
May 76	18.9	12	226.8	18.6	13	241.8	12.9	61	786.9	12.0	51	612.0
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	24.6	19	467.4	20.6	31	638.6	16.7	35	584.5	16.2	59	955.8
Aug 76	22.5	30	675.0	19.8	33	653.4	16.5	51	841.5	15.6	65	1014.0
Sep 76	26.7	15	400.5	21.4	19	406.6	17.4	40	696.0	17.1	48	820.8
Oct 76	23.9	25	597.5	20.0	37	740.0	17.1	49	837.9	17.3	69	1193.7
Nov 76	22.4	36	806.4	20.1	34	683.4	16.8	48	806.4	16.1	36	579.6
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		206	4536.2		277	5430.7		506	7799.1		603	9277.4
AVG			22.02			19.61			15.41			15.39

Table C4

Single Exchange Exit Times

L&D 26 - Present Locks

Month	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	0	0	--	0	0	--	6.1	22	134.2	4.5	19	85.5
Nov 75	10.8	5	54.0	12.0	4	48.0	4.0	4	16.0	5.4	11	59.4
Dec 75	8.7	6	52.2	10.9	19	207.1	4.2	9	37.8	3.0	5	15.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	7.0	3	21.0	11.6	9	104.4	3.9	7	27.3	6.7	6	40.2
Mar 76	12.3	7	86.1	14.5	6	87.0	4.0	12	48.0	4.5	10	45.0
Apr 76	11.5	2	23.0	11.0	2	22.0	6.5	11	71.5	6.9	9	62.1
May 76	7.8	4	31.2	7.4	5	37.0	4.0	15	60.0	6.1	11	67.1
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	18.0	7	126.0	10.1	14	141.4	3.2	9	28.8	5.5	12	66.0
Aug 76	7.7	14	107.8	9.2	13	119.6	5.5	11	60.5	5.2	13	67.6
Sep 76	9.3	4	37.2	11.8	11	129.8	5.1	7	35.7	7.3	6	43.8
Oct 76	14.8	4	59.2	9.3	15	139.5	4.4	16	70.4	4.5	21	94.5
Nov 76	10.7	14	149.8	9.0	15	135.0	4.8	12	57.6	3.7	6	22.2
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		70	747.5		113	1170.8		135	647.8		129	668.4
AVG			10.68			10.36			4.80			5.18

Table C5

Single Turnback Exit Times

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	12.3	4	49.2	0	0	--	2.1	8	16.8	3.2	11	35.2
Nov 75	6.2	5	31.0	5.7	6	34.2	2.3	4	9.2	3.3	9	29.7
Dec 75	7.6	5	38.0	5.7	24	136.8	10.2	6	61.2	2.0	5	10.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	6.6	5	33.0	7.7	6	46.2	2.8	5	14.0	6.6	8	52.8
Mar 76	7.8	10	78.0	6.6	12	79.2	2.4	7	16.8	4.3	7	30.1
Apr 76	5.8	4	23.2	5.4	8	43.2	2.4	5	12.0	5.6	13	72.8
May 76	7.4	8	59.2	5.1	8	40.8	4.3	15	64.5	2.6	10	26.0
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	4.6	10	46.0	6.3	15	94.5	3.5	6	21.0	2.9	8	23.2
Aug 76	5.3	12	63.6	7.5	16	120.0	2.3	6	13.8	2.8	10	28.0
Sep 76	5.9	11	64.9	7.4	8	59.2	3.5	8	28.0	2.3	9	20.7
Oct 76	6.4	17	108.8	7.4	18	133.2	2.6	8	20.8	2.3	6	13.8
Nov 76	7.0	9	63.0	4.9	9	44.1	2.7	6	16.2	6.0	2	12.0
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		100	657.9		130	831.4		84	294.3		98	354.3
AVG			6.58			6.40			3.50			3.62

Table C6

Standard Setover/Knockout Exchange Approach

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	19.5	4	78.0	0	0	--	16.8	8	134.4	19.0	6	114.0
	0	0	--	25.0	1	25.0	0	0	--	11.7	3	35.1
Nov 75	21.2	6	127.2	18.0	1	18.0	14.7	13	191.1	8.5	6	51.0
	18.8	4	75.2	12.5	2	25.0	0	0	--	0	0	--
Dec 75	28.4	10	284.0	17.0	3	51.0	20.0	2	40.0	29.0	1	29.0
	15.4	5	77.0	23.4	5	117.0	14.7	3	44.1	3.0	1	3.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	15.8	4	63.2	14.0	1	14.0	13.2	5	66.0	21.0	2	42.0
	17.3	3	51.9	21.0	11	231.0	25.0	1	25.0	--	--	--
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Jul 76	21.0	6	126.0	13.0	1	13.0	7.7	6	46.2	16.3	3	48.9
	17.4	5	87.0	27.0	2	54.0	0	0	--	12.3	3	36.9
Aug 76	26.8	4	107.2	18.3	3	54.9	11.0	2	22.0	9.5	4	38.0
	17.0	6	102.0	26.8	4	107.2	12.5	2	25.0	15.5	2	31.0
Sep 76	22.2	6	133.2	20.0	2	40.0	26.5	4	106.0	21.0	1	21.0
	13.4	5	67.0	15.3	8	122.4	0	0	--	0	0	--
Oct 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		68	1378.9		44	872.5		46	699.8		32	449.9
AVG			20.28			19.83			15.21			14.06

Table C7

Standard Setover/Knockout Turnback Approach

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	2.5	15	37.5	1.0	3	3.0	7.8	5	14.0	1.5	2	3.0
	7.1	7	49.7	1.4	5	7.0	8.0	1	8.0	0	0	--
Nov 75	2.8	9	25.2	9.0	2	18.0	11.0	2	22.0	1.5	2	3.0
	2.3	6	13.8	2.0	6	12.0	2.0	1	2.0	1.0	1	1.0
Dec 75	3.6	16	57.6	1.0	1	1.0	3.5	2	7.0	1.0	1	1.0
	2.7	14	37.8	1.2	18	21.6	0	0	--	1.0	2	2.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	2.7	10	27.0	1.0	3	3.0	2.6	5	13.0	3.7	3	11.1
	2.0	10	20.0	1.8	8	14.4	3.0	1	3.0	1.0	1	1.0
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Jul 76	2.4	19	45.6	1.1	8	8.8	2.9	8	23.2	10.2	5	51.0
	3.2	10	32.0	1.6	9	14.4	0	0	--	3.0	1	3.0
Aug 76	3.4	17	57.8	1.7	6	10.2	40.0	2	80.0	1.2	6	7.2
	2.1	18	37.8	1.5	11	16.5	1.0	1	1.0	1.0	1	1.0
Sep 76	4.4	15	66.0	1.6	8	12.8	3.0	3	9.0	1.5	2	3.0
	2.2	18	39.6	1.3	8	10.4	7.0	2	14.0	11.5	2	23.0
Oct 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		184	547.4		96	153.1		33	196.2		29	110.2
AVG			2.98			1.59			5.95			3.80

Table C8

Standard Setover/Knockout Chambering Times

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	34.8	19	661.2	40.7	3	122.1	34.9	15	523.5	20.3	11	223.3
	30.7	7	214.9	28.0	6	168.0	25.0	1	25.0	26.0	7	182.0
Nov 75	36.3	15	544.5	38.3	3	114.9	19.9	20	398.0	28.0	13	364.0
	19.9	11	218.9	26.9	8	215.2	17.5	2	35.0	30.6	4	122.4
Dec 75	34.6	31	1072.6	27.8	5	139.0	28.9	9	260.1	24.9	11	273.9
	29.5	23	678.5	27.8	25	695.0	26.1	4	104.4	29.5	4	118.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	33.9	14	474.6	31.0	4	124.0	34.6	13	449.8	31.9	6	191.4
	28.2	13	366.6	27.5	19	522.5	33.0	2	66.0	25.0	1	25.0
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Jul 76	38.7	25	967.5	29.4	9	264.6	36.0	20	720.0	28.0	13	364.0
	32.9	15	493.5	27.0	11	297.0	0	0	--	31.0	5	155.0
Aug 76	39.9	22	877.8	30.5	10	305.0	39.4	9	354.6	27.0	17	459.0
	29.7	26	772.2	26.8	17	455.6	31.8	4	127.2	31.4	5	157.0
Sep 76	40.6	22	893.2	32.4	10	324.0	32.1	18	577.8	76.7	11	843.7
	32.0	23	736.0	26.9	18	484.2	27.4	3	82.2	46.5	2	93.0
Oct 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		266	8972.0		148	4231.1		120	3723.6		110	3571.7
AVG			33.73			28.56			31.03			32.47

Table C9

Standard Setover/Knockout Exchange Exit

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	34.3	9	308.7	38.5	2	77.0	23.8	5	119.0	9.0	2	18.0
	15.5	10	155.0	21.0	1	21.0	13.0	1	13.0	5.0	1	5.0
Nov 75	38.7	3	116.1	0	0	--	29.5	11	324.5	16.5	2	33.0
	17.5	12	210.0	21.5	3	64.5	0	0	--	15.5	2	31.0
Dec 75	30.2	12	362.4	32.0	1	32.0	42.5	2	85.0	40.5	2	81.0
	18.4	10	184.0	17.4	12	208.8	13.7	3	41.1	30.0	1	30.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	28.5	4	114.0	0	0	--	25.8	4	103.2	14.0	2	28.0
	14.0	3	42.0	17.3	6	103.8	10.0	2	20.0	0	0	--
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Jul 76	26.0	6	156.0	22.0	4	88.0	20.4	8	163.2	14.0	4	56.0
	14.3	3	42.9	23.7	3	71.1	0	0	--	12.0	1	12.0
Aug 76	24.3	4	97.2	30.0	3	90.0	20.7	3	62.1	12.3	3	36.9
	15.5	8	124.0	18.8	4	75.2	21.0	2	42.0	12.7	3	38.1
Sep 76	32.9	7	230.3	26.2	5	131.0	25.1	7	175.7	17.0	1	17.0
	16.1	8	128.8	17.4	5	87.0	0	0	--	0	0	--
Oct 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		99	2271.4		49	1049.4		48	1148.8		24	386.0
AVG			22.94			21.42			23.93			16.08

Table C10

Standard Setover/Knockout Turnback Exit

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	26.9	10	269.0	20.0	1	20.0	25.2	5	126.0	13.6	5	68.0
	12.7	3	38.1	14.3	4	57.2	0	0	--	10.7	3	32.1
Nov 75	34.1	12	409.2	22.7	3	68.1	32.0	5	160.0	14.6	5	73.0
	20.3	6	121.8	12.3	3	36.9	0	0	--	6.0	1	6.0
Dec 75	30.1	16	481.6	11.7	3	35.1	22.5	2	45.0	0	0	--
	13.4	11	147.4	13.7	9	123.3	0	0	--	0	0	--
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	29.3	10	293.0	18.5	4	74.0	29.8	6	178.8	16.5	2	33.0
	11.4	10	114.0	14.4	12	172.8	0	0	--	9.0	1	9.0
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Jul 76	12.2	18	219.6	13.4	5	67.0	23.2	6	139.2	5.5	4	22.0
	9.9	11	108.9	16.9	7	118.3	0	0	--	7.0	1	7.0
Aug 76	14.8	17	251.6	9.1	7	63.7	21.0	1	21.0	12.2	6	73.2
	11.1	17	188.7	10.7	11	117.7	0	0	--	0	0	--
Sep 76	14.5	13	188.5	11.2	5	56.0	32.0	3	96.0	13.0	3	39.0
	10.7	15	160.5	13.4	12	160.8	17.0	1	17.0	27.0	1	27.0
Oct 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		169	2991.9		86	1170.9		29	783.0		32	389.3
AVG			17.70			13.62			27.0			12.17

Table C11

Standard Doubles Exchange Approach

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	23.2	49	1136.8	23.3	57	1328.1	14.9	24	357.6	16.4	26	426.4
Nov 75	25.2	48	1209.6	23.8	52	1237.6	14.9	38	566.2	21.6	30	648.0
Dec 75	21.4	40	856.0	22.3	41	914.3	15.3	12	183.6	21.0	19	399.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	25.2	52	1310.4	27.4	46	1260.4	20.4	9	183.6	21.9	21	459.9
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	19.4	35	679.0	24.9	38	946.2	13.9	8	111.2	9.0	10	90.0
Aug 76	23.9	40	956.0	26.2	44	1152.8	14.7	15	220.5	13.5	13	175.5
Sep 76	20.1	38	763.8	24.4	39	951.6	9.8	13	127.4	18.2	13	236.6
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		302	6911.6		317	7791.0		119	1750.1		132	2435.4
AVG			22.89			24.58			14.71			18.45

Table C12

Standard Doubles Turnback Approach

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	1.9	89	169.1	2.7	115	310.5	8.2	13	106.6	6.3	23	114.9
Nov 75	2.5	83	207.5	1.9	105	199.5	20.3	15	304.5	2.8	17	47.6
Dec 75	3.3	78	257.4	2.1	70	147.0	9.2	5	46.0	7.8	18	140.4
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	2.3	89	204.7	3.7	86	318.2	6.4	16	102.4	6.2	33	204.6
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	2.5	125	312.5	2.2	121	266.2	5.8	8	46.4	1.6	14	22.4
Aug 76	2.8	102	285.6	2.1	101	212.1	1.8	4	7.2	3.0	12	36.0
Sep 76	3.1	115	356.5	1.9	102	193.8	6.8	18	122.4	8.7	6	52.2
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		681	1793.3		700	1647.3		79	735.5		123	648.1
AVG			2.63			2.35			9.31			5.27

Table C13

Standard Doubles Chambering

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	76.4	141	10772.4	87.4	174	15207.6	70.8	50	3540.0	64.2	69	4429.8
Nov 75	78.5	135	10597.5	97.2	161	15649.9	73.2	68	4977.6	61.2	61	3733.2
Dec 75	69.9	133	9296.7	74.1	121	8966.1	62.8	32	2009.6	52.8	64	3379.2
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	72.5	142	10295.0	89.7	134	12019.8	84.3	30	2529.0	69.8	65	4537.0
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	74.1	164	12152.4	79.3	163	12925.9	64.1	37	2371.7	58.1	44	2556.4
Aug 76	76.9	149	11458.1	83.6	148	12372.8	64.0	31	1984.0	59.2	50	2960.0
Sep 76	81.5	154	12551.0	80.8	143	11554.4	69.2	43	2975.6	56.3	45	2533.5
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		1018	77123.1		1044	88695.8		291	20387.5		398	24129.1
AVG			75.76			84.96			70.06			60.63

Table C14

Standard Doubles Exchange Exit

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	29.8	46	1370.8	28.7	54	1549.8	27.3	25	682.5	23.1	42	970.2
Nov 75	32.6	44	1434.4	32.3	53	1711.9	25.9	40	1036.0	21.8	37	806.6
Dec 75	30.2	34	1026.8	32.0	30	960.0	24.0	14	336.0	16.7	23	384.1
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	31.2	52	1622.4	34.2	44	1504.8	26.8	11	294.8	24.3	18	437.4
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	19.6	33	646.8	27.8	28	778.4	15.4	11	169.4	12.5	6	75.0
Aug 76	20.0	33	660.0	28.7	36	1033.2	18.9	17	321.3	18.9	16	302.4
Sep 76	23.2	32	742.4	30.5	33	1006.5	16.9	17	287.3	18.8	15	282.0
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		274	7503.6		278	8544.6		135	3127.3		157	3257.7
AVG			27.39			30.74			23.17			20.75

Table C15

Standard Doubles Turnback Exit

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	22.5	94	2115.0	21.5	118	2537.0	17.3	10	173.0	13.2	17	224.4
Nov 75	24.1	87	2096.7	23.5	107	2514.5	18.9	17	321.3	10.9	14	152.6
Dec 75	22.1	84	1856.4	23.1	84	1940.4	10.0	1	10.0	15.9	20	318.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	23.1	88	2032.8	21.5	89	1913.5	37.6	16	601.6	16.4	38	623.2
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	9.0	128	1152.0	11.6	131	1519.6	22.4	10	224.0	10.6	17	180.2
Aug 76	12.9	112	1444.8	15.8	108	1706.4	12.8	4	51.2	14.2	17	241.4
Sep 76	11.8	120	1416.0	13.4	107	1433.8	14.7	19	279.3	14.1	10	141.0
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		713	12113.7		744	13565.2		77	1660.4		133	1880.8
AVG			16.99			18.23			21.56			14.14

Table C16

Standard Multi-Cut >2 Exchange Approach

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	0	0	--	27.0	1	27.0	13.8	13	179.4	25.4	15	381.0
Nov 75	--	--	--	--	--	--	17.6	17	299.2	22.9	19	435.0
Dec 75	--	--	--	--	--	--	11.0	1	11.0	27.5	2	55.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	0	0	--	68.0	1	68.0	18.4	16	294.4	31.8	9	286.2
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	24.0	1	24.0	0	0	--	24.8	4	99.2	22.5	2	45.0
Aug 76	--	--	--	--	--	--	20.8	5	104.0	34.5	2	69.0
Sep 76	--	--	--	--	--	--	8.0	1	8.0	8.0	1	8.0
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		1	24.0		2	95.0		57	995.2		50	1279.3
AVG			24.0			47.5			17.5			25.6

Table C17

Standard Multi-Cut $\geq$2 Turnback Approach

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg. × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	0	0	--	8.0	1	8.0	24.7	3	74.1	18.2	5	91.0
Nov 75	--	--	--	--	--	--	2.0	6	12.0	18.1	15	271.5
Dec 75	--	--	--	--	--	--	0	0	--	10.5	2	21.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	0	0	--	7.0	1	7.0	4.7	13	61.1	8.5	19	161.5
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	--	--	--	--	--	--	2.0	2	4.0	1.5	2	3.0
Aug 76	--	--	--	--	--	--	1.0	1	1.0	7.0	4	28.0
Sep 76	--	--	--	--	--	--	2.3	4	9.2	13.7	3	41.1
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL					2	15.0		29	161.4		50	617.5
AVG						7.5			5.57			12.35

Table C18

Standard Multi-Cut >2 Chambering

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	0	0	--	74.0	2	148.0	157.4	21	3305.4	166.6	27	4498.2
Nov 75	--	--	--	--	--	--	153.8	24	3691.2	164.6	34	5596.4
Dec 75	--	--	--	--	--	--	159.5	2	319.0	136.8	6	820.8
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	0	0	--	199.5	2	399.0	153.9	33	5078.7	164.6	32	526.72
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	69.0	1	69.0	--	--	--	157.2	11	1729.2	130.2	5	651.0
Aug 76	--	--	--	--	--	--	139.4	8	1115.2	138.2	11	1520.2
Sep 76	--	--	--	--	--	--	128.5	9	1156.5	118.5	7	829.5
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		1	69.0		4	547.0		108	16395.2		122	19183.3
AVG			69.0			136.75			151.81			157.24

Table C19

Standard Multi-Cut >2 Exchange Exit

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	0	0	--	0	0	--	21.0	14	294.0	24.7	19	469.3
Nov 75	--	--	--	--	--	--	27.0	18	486.0	30.8	22	677.6
Dec 75	--	--	--	--	--	--	17.0	1	17.0	23.7	3	71.1
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	0	0	--	55.0	1	55.0	31.3	17	532.1	45.4	14	635.6
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	20.0	1	20.0	--	--	--	17.2	5	86.0	14.0	3	42.0
Aug 76	--	--	--	--	--	--	22.4	5	112.0	31.7	3	95.1
Sep 76	--	--	--	--	--	--	23.5	4	94.0	18.5	6	111.0
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		1	20.0		1	55.0		64	1621.1		70	2101.7
AVG			20.0			55.0			25.33			30.02

Table C20

Standard Multi-Cut >2 Turnback Exit

L&D 26 - Present Locks

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	0	0	--	4.0	2	8.0	22.6	5	112.5	17.8	6	106.8
Nov 75	--	--	--	--	--	--	15.3	3	45.9	23.3	10	233.0
Dec 75	--	--	--	--	--	--	12.0	1	12.0	27.5	2	55.0
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	0	0	--	9.0	1	9.0	36.1	14	505.4	28.9	15	433.5
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	--	--	--	--	--	--	--	--	--	--	--	--
May 76	--	--	--	--	--	--	--	--	--	--	--	--
Jun 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jul 76	--	--	--	--	--	--	14.5	4	58.0	16.0	2	32.0
Aug 76	--	--	--	--	--	--	20.5	2	41.0	7.7	3	23.1
Sep 76	--	--	--	--	--	--	14.0	3	42.0	23.0	1	23.0
Oct 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Nov 76	--	--	--	--	--	--	--	--	--	--	--	--
Dec 76	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Jan 77	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL					3	17.0		32	816.8		39	906.4
AVG						5.67			25.53			23.24

Table C21

Single Standard Approach Times

L&D 25

	Exchange						Turnback					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	10.1	8	80.8	18.7	7	130.9	5.9	8	47.2	3.5	21	73.5
Nov 75	13.4	7	93.8	16.9	7	118.3	2.1	12	25.2	3.8	13	49.4
Dec 75	--	--	--	--	--	--	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	16.0	7	112.0	13.6	10	136.0	3.5	2	7.0	6.7	20	134.0
May 76	10.2	10	102.0	13.8	11	151.8	2.6	9	23.4	11.4	10	114.0
Jul 76	8.7	11	95.7	10.3	16	164.8	1.2	6	7.2	2.8	8	22.4
Aug 76	10.0	9	90.0	9.7	12	116.4	3.4	5	17.0	2.6	17	44.2
Sep 76	5.8	5	29.0	10.7	6	64.2	1.5	2	3.0	1.9	7	13.3
Oct 76	10.6	5	53.0	12.2	11	134.2	3.8	10	38.0	3.4	9	30.6
Nov 76	12.6	12	151.2	15.4	10	154.0	1.7	9	15.3	2.3	21	48.3
TOTAL		74	807.5		90	1170.6		63	183.3		126	529.7
AVG	10.91			13.01			2.91			4.2		

Table C22

Single Standard Chambering Times

L&D 25

	Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	16.2	28	453.6	15.3	44	673.2
Nov 75	15.4	36	554.4	14.1	33	465.3
Dec 75	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--
Apr 76	9.7	26	252.2	11.1	43	477.3
May 76	11.8	29	342.2	12.4	34	421.6
Jul 76	15.7	29	455.3	13.8	37	510.6
Aug 76	16.1	20	322.0	14.7	42	617.4
Sep 76	17.1	14	239.4	14.3	28	400.4
Oct 76	17.4	26	452.4	14.9	43	640.7
Nov 76	16.8	35	588.0	15.5	43	666.5
TOTAL		243	3659.5		347	4873.0
AVG	15.06			14.04		

NOTE: Chambering times shown above are the sum of the chamber entry and chambering times as provided by PMS.

Table C23

Single Standard Exit Times

L&D 25

	Exchange						Turnback					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	2.0	5	10.0	3.6	9	32.4	4.6	5	23.0	4.7	15	70.5
Nov 75	5.9	7	41.3	4.2	9	37.8	3.2	6	19.2	3.7	7	25.9
Dec 75	--	--	--	--	--	--	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	2.8	5	14.0	4.2	6	25.2	7.3	7	51.1	5.1	11	56.1
May 76	4.4	8	35.2	3.9	8	31.2	3.3	4	13.2	2.7	6	16.2
Jul 76	3.8	15	57.0	4.9	15	73.5	3.7	3	11.1	3.9	8	31.2
Aug 76	3.7	9	33.3	5.6	11	61.6	6.0	1	6.0	4.6	11	50.6
Sep 76	4.4	5	22.0	2.0	2	4.0	2.0	1	2.0	4.8	8	38.4
Oct 76	3.3	10	33.0	4.1	8	32.8	3.8	4	15.2	4.4	8	35.2
Nov 76	4.3	8	34.4	5.1	11	56.1	4.0	3	12.0	4.0	17	68.0
TOTAL		72	280.2		79	354.6		34	152.8		91	392.1
AVG	3.89			4.49			4.49			4.31		

Table C24

Double Standard Approach Times

L&D 25

Month	Exchange						Turnback					
	Up Direction			Down Direction			Up Direction			Down Direction		
	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	16.7	24	400.8	20.8	27	561.6	2.4	22	52.8	7.4	30	222.0
Nov 75	18.7	29	542.3	24.8	31	768.8	4.6	8	36.8	3.5	13	45.5
Dec 75	--	--	--	--	--	--	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	28.5	15	427.5	45.8	22	1007.6	6.2	35	217.0	24.4	20	488.0
May 76	16.6	35	581.0	33.7	39	1314.3	3.0	36	108.0	8.8	27	237.6
Jul 76	14.8	41	606.8	17.8	28	498.4	2.5	22	55.0	5.6	24	134.4
Aug 76	18.0	27	486.0	21.4	24	513.6	2.7	17	45.9	6.0	29	174.0
Sep 76	16.4	28	459.2	21.2	20	424.0	3.0	17	51.0	6.4	19	121.6
Oct 76	21.9	26	569.4	26.5	29	768.5	5.4	18	97.2	6.6	20	132.0
Nov 76	19.9	21	417.9	23.3	23	535.9	2.2	19	41.8	6.9	19	131.1
TOTAL		246	4490.9		243	6392.7		194	705.5		201	1686.2
AVG	18.26			26.31			3.64			8.39		

Table C25

Double Standard Chambering Times

L&D 25

	Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	73.8	72	5313.6	77.8	90	7002.0
Nov 75	72.1	58	4181.8	74.3	79	5869.7
Dec 75	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--
Apr 76	52.4	92	4820.8	57.6	82	4723.2
May 76	57.2	102	5834.4	64.5	104	6708.0
Jul 76	68.5	90	6165.0	76.3	88	6714.4
Aug 76	70.6	76	5365.6	76.3	75	5722.5
Sep 76	75.5	79	5964.5	72.3	68	4916.4
Oct 76	73.9	80	5912.0	72.7	88	6397.6
Nov 76	69.3	69	4781.7	74.0	94	6956.0
TOTAL		718	48339.4		768	55009.8
AVG	67.33			71.63		

NOTE: Chambering times shown above are the sum of the chamber entry and chambering times as provided by PMS.

Table C26

Double Standard Exit Times

L&D 25

	Exchange						Turnback					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75	17.9	22	393.8	20.9	32	668.8	20.5	30	615.0	23.3	40	932.0
Nov 75	21.1	23	485.3	24.9	29	722.1	17.3	15	259.5	20.1	25	502.5
Dec 75	--	--	--	--	--	--	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76	19.2	28	537.6	18.2	22	400.4	17.5	29	507.5	18.7	28	523.6
May 76	17.0	42	714.0	20.6	41	844.6	17.6	38	668.8	20.3	29	588.7
Jul 76	17.8	44	783.2	21.2	49	1038.8	16.7	22	367.4	22.9	23	526.7
Aug 76	17.5	37	647.5	20.9	42	877.8	17.1	17	290.7	19.4	24	465.6
Sep 76	18.8	33	620.4	22.8	23	524.4	19.3	16	308.8	18.4	28	515.2
Oct 76	17.8	30	534.0	21.7	25	542.5	17.8	21	373.8	25.4	28	711.2
Nov 76	15.4	21	323.4	21.8	30	654.0	17.0	19	323.0	20.8	23	478.4
TOTAL		280	5039.2		293	6273.4		207	3714.5		248	4054.3
AVG	18.0			21.41			17.94			16.35		

Table C27

Setover an Knockout Standard Approach Times

L&D 25

	Exchange						Turnback					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75												
Setover	16.8	4	67.2	17.0	1	17.0	4.1	7	28.7	1.0	2	2.0
Knockout	11.0	7	77.0	18.7	3	56.1	2.0	2	4.0	13.0	2	26.0
Nov 75												
Setover	19.3	6	115.8	0	0	--	2.8	4	11.2	0	0	--
Knockout	13.0	5	65.0	15.0	3	45.0	2.0	5	10.0	5.0	4	20.0
Dec 75	--	--	--	--	--	--	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76												
Setover	18.5	4	74.0	0	0	--	5.6	9	50.4	0	0	--
Knockout	17.0	3	51.0	32.1	8	256.8	1.0	1	1.0	15.8	4	63.2
May 76												
Setover	18.1	7	126.7	0	0	--	2.9	7	20.3	0	0	--
Knockout	30.0	1	30.0	22.2	5	111.0	1.7	3	5.1	3.0	3	9.0
Jul 76												
Setover	13.8	9	124.2	23.0	1	23.0	2.9	7	20.3	2.0	2	4.0
Knockout	9.0	4	36.0	16.9	7	118.3	4.7	6	28.2	6.0	4	24.0

(Continued)

Table C27 (Concluded)

	Exchange						Turnback					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Aug 76												
Setover	14.4	5	72.0	8.5	4	34.0	3.1	7	21.7	0	0	--
Knockout	11.0	3	33.0	11.3	3	33.9	4.5	6	27.0	15.3	3	45.9
Sep 76												
Setover	15.2	5	76.0	0	0	--	1.8	5	9.0	2.0	2	4.0
Knockout	16.0	2	32.0	16.4	9	147.6	2.8	6	16.8	2.1	7	14.7
Oct 76												
Setover	20.5	6	123.0	0	0	--	3.5	6	21.0	1.0	1	1.0
Knockout	7.3	4	29.2	21.6	5	108.0	2.6	5	13.0	3.4	7	23.8
Nov 76												
Setover	19.6	10	196.0	0	0	--	3.0	3	9.0	8.0	1	8.0
Knockout	20.0	2	40.0	14.3	3	42.9	2.0	2	4.0	1.0	1	1.0
TOTAL		87	1368.1		52	993.6		91	300.7		43	246.6
AVG	15.73			19.11			3.3			5.73		

Table C28

Setover and Knockout Standard Chambering Times

L&D 25

Month	Up Direction Avg Time	No. Incl.	Avg × No.	Down Direction Avg Time	No. Incl.	Avg × No.
Oct 75						
Setover	33.0	18	594.0	31.0	3	93.0
Knockout	25.8	14	361.2	23.1	8	184.8
Nov 75						
Setover	30.0	20	600.0	22.0	2	44.0
Knockout	26.1	20	522.0	21.0	10	210.0
Dec 75	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--
Apr 76						
Setover	22.3	13	289.9	25.0	1	25.0
Knockout	18.5	13	240.5	18.9	18	340.2
May 76						
Setover	32.1	19	609.9	12.0	1	12.0
Knockout	17.5	8	140.0	18.9	12	226.8
Jul 76						
Setover	29.1	18	523.8	29.7	3	89.1
Knockout	24.5	17	416.5	25.0	15	375.0
Aug 76						
Setover	35.3	19	670.7	26.0	5	130.0
Knockout	24.2	13	314.6	24.0	10	240.0
Sep 76	31.2	14	436.8	24.0	2	48.0
Setover	31.2	14	436.8	24.0	2	48.0
Knockout	24.8	13	322.4	21.4	21	449.4
Oct 76						
Setover	30.5	19	579.5	27.0	1	27.0
Knockout	27.0	17	459.0	21.8	15	327.0
Nov 76						
Setover	32.5	22	715.0	19.0	1	19.0
Knockout	24.6	11	270.6	20.3	9	182.7
TOTAL		288	8066.4		137	3023.0
AVG	28.01			22.07		

NOTE: Chambering times shown above are the sum of the chamber entry and chambering times as provided by PMS.

Table C29

Setover and Knockout Standard Exit Times

L&D 25

	Exchange						Turnback					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 75												
Setover	25.0	7	175.0	0	0	--	26.7	3	80.1	38.0	3	114.0
Knockout	17.0	1	17.0	13.0	2	26.0	8.0	5	40.0	14.0	3	42.0
Nov 75												
Setover	29.0	10	290.0	0	0	--	32.5	2	65.0	0	0	--
Knockout	12.8	4	51.2	8.5	2	17.0	10.7	3	32.1	10.0	1	10.0
Dec 75	--	--	--	--	--	--	--	--	--	--	--	--
Jan 76	--	--	--	--	--	--	--	--	--	--	--	--
Feb 76	--	--	--	--	--	--	--	--	--	--	--	--
Mar 76	--	--	--	--	--	--	--	--	--	--	--	--
Apr 76												
Setover	24.5	2	49.0	0	0	--	30.3	7	212.1	0	0	--
Knockout	13.0	1	13.0	11.5	6	69.0	10.3	3	30.9	13.0	3	39.0
May 76												
Setover	30.9	8	247.2	5.0	1	5.0	23.2	9	208.8	0	0	--
Knockout	10.5	4	42.0	10.7	7	74.9	4.0	1	4.0	9.5	4	38.0
Jul 76												
Setover	25.2	6	151.2	39.0	1	39.0	30.8	4	123.2	0	0	--
Knockout	13.0	4	52.0	13.3	8	106.4	12.5	4	50.0	17.0	1	17.0

(Continued)

Table C29 (Concluded)

	Exchange						Turnback					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Aug 76												
Setover	28.2	6	169.2	35.3	3	105.9	27.6	8	220.8	35.0	1	35.0
Knockout	14.7	3	44.1	13.3	4	53.2	9.7	3	29.1	13.3	4	53.2
Sep 76												
Setover	28.6	5	143.0	13.0	1	13.0	27.4	5	137.0	0	0	--
Knockout	6.7	3	20.1	12.9	8	103.2	8.8	4	35.2	16.4	7	114.8
Oct 76												
Setover	24.8	6	148.8	13.0	1	13.0	24.4	8	195.2	0	0	--
Knockout	9.3	7	65.1	14.3	4	57.2	6.0	3	18.0	14.3	6	85.8
Nov 76												
Setover	32.9	7	230.3	0	0	--	26.6	7	186.2	0	0	--
Knockout	10.0	3	30.0	11.7	3	35.1	13.0	3	39.0	11.5	2	23.0
TOTAL		87	1938.2		51	717.9		82	1706.7		35	571.8
AVG	22.28			14.08			20.81			16.34		

Table C30

Single Other Vessel Processing Times

L&D 25

	Up Direction		
Month	Avg Time	No. Incl.	Avg × No.
Oct 75	13.2	79	1042.8
Nov 75	13.4	25	335.0
Dec 75	--	--	--
Jan 76	--	--	--
Feb 76	--	--	--
Mar 76	--	--	--
Apr 76	17.4	43	748.2
May 76	13.7	91	1246.7
Jul 76	12.9	311	4011.9
Aug 76	13.0	264	3432.0
Sep 76	13.7	200	2740.0
Oct 76	13.4	83	1112.2
Nov 76	14.9	16	238.4
TOTAL		1112	14907.2
AVG	13.41		

Table C31

Single Standard Approach Times

L&D 27 - After Guidewall Extension

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
			Exchange						Exchange			
Oct 76	16.2	60	972.0	16.0	69	1104.0	5.6	16	89.6	9.8	11	107.8
Nov 76	12.6	77	970.2	16.5	80	1320.0	10.1	16	161.6	15.3	12	183.6
TOTAL		137	1942.2		149	2424.0		32	251.2		23	291.4
AVG	14.18			16.27			7.85			12.67		
			Turnback						Turnback			
Oct 76	5.4	121	653.4	4.2	111	466.2	4.2	12	50.4	3.1	15	46.5
Nov 76	3.8	63	239.4	4.5	81	364.5	2.0	4	8.0	6.7	9	60.3
TOTAL		184	892.8		192	830.7		16	58.4		24	106.8
AVG	4.85			4.33			3.65			4.45		

Table C32

Single Standard Chambering Times

L&D 27 - After Guidewall Extension

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 76	21.8	265	5777.0	20.6	260	5356.0	13.7	90	1233.0	15.6	114	1778.4
Nov 76	20.4	242	4936.8	20.4	274	5589.6	14.0	103	1442.0	15.4	113	1740.2
TOTAL		507	10713.8		534	10945.6		193	2675.0		227	3518.6
AVG	21.13			20.5			13.86			15.5		

NOTE: Chambering times shown above are the sum of the chamber entry and chambering times as provided by PMS.

Table C33

Single Standard Exit Times

L&D 27 - After Guidewall Extension

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
			Exchange							Exchange		
Oct 76	9.3	81	753.3	9.9	55	544.5	5.8	18	104.4	4.3	11	47.3
Nov 76	9.9	73	722.7	10.4	87	904.8	4.6	18	82.8	5.2	16	83.2
TOTAL		154	1476.0		142	1449.3		36	187.2		27	130.5
AVG	9.58			10.21			5.2			4.83		
			Turnback							Turnback		
Oct 76	8.3	119	987.7	7.9	107	845.3	4.9	14	68.6	4.5	15	67.5
Nov 76	6.6	63	415.8	8.1	86	696.6	4.2	6	25.2	4.2	10	42.0
TOTAL		182	1403.5		193	1541.9		20	93.8		25	109.5
AVG	7.71			7.99			4.69			4.38		

Table C34

Setover and Knockout Standard Approach Times

L&D 27 - After Guidewall Extension

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
			Exchange						Exchange			
Oct 76												
Setover	--	--	--	--	--	--	--	--	--	--	--	--
Knockout	--	--	--	--	--	--	2.0	1	2.0	8.0	2	16.0
Nov 76												
Setover	--	--	--	--	--	--	--	--	--	--	--	--
Knockout	--	--	--	--	--	--	10.0	1	10.0	--	--	--
TOTAL	--	--	--	--	--	--		2	12.0		2	16.0
AVG	--	--	--	--	--	--	6.0			8.0		
			Turnback						Turnback			
Oct 76												
Setover	--	--	--	--	--	--	--	--	--	--	--	--
Knockout	--	--	--	--	--	--	3.0	4	12.0	3.0	3	9.0
Nov 76												
Setover	8.0	1	8.0	--	--	--	--	--	--	--	--	--
Knockout	2.0	1	2.0	--	--	--	--	--	--	2.0	1	2.0
TOTAL		2	10.0	--	--	--		4	12.0		4	11.0
AVG	5.0			--	--	--	3.0			2.75		

Table C35

Setover and Knockout Standard Chambering Times

L&D 27 - After Guidewall Extension

Month	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 76												
Setover	--	--	--	--	--	--	--	--	--	--	--	--
Knockout	34.0	1	34.0	--	--	--	25.9	10	259.0	22.9	8	183.2
Nov 76												
Setover	24.0	1	24.0	--	--	--	--	--	--	--	--	--
Knockout	25.5	2	51.0	--	--	--	24.5	4	98.0	22.2	5	111.0
TOTAL		4	109.0	--	--	--		14	357.0		13	294.2
AVG	27.25			--	--	--	25.5			22.63		

NOTE: Chambering times shown above are the sum of the chamber entry and chambering times as provided by PMS.

Table C36

Setover and Knockout Standard Exit Times

L&D 27 - After Guidewall Extension

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
			Exchange						Exchange			
Oct 76												
Setover	--	--	--	--	--	--	--	--	--	--	--	--
Knockout	--	--	--	--	--	--	11.3	3	33.9	10.3	2	20.6
Nov 76												
Setover	--	--	--	--	--	--	--	--	--	--	--	--
Knockout	9.0	2	18.0	--	--	--	--	--	--	--	--	--
TOTAL		2	18.0	--	--	--		3	33.9		2	20.6
AVG	9.0			--	--	--	11.3			10.3		
			Turnback						Turnback			
Oct 76												
Setover	--	--	--	--	--	--	--	--	--	--	--	--
Knockout	15.0	1	15.0	--	--	--	10.3	4	41.2	8.3	3	24.9
Nov 76												
Setover	12.0	1	12.0	--	--	--	--	--	--	--	--	--
Knockout	--	--	--	--	--	--	--	--	--	--	--	--
TOTAL		2	27.0	--	--	--		4	41.2		3	24.9
AVG	13.5			--	--	--	10.3			8.3		

Table C37

Multi-Vessel Standard Approach Times

L&D 27 - After Guidewall Extension

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
			Exchange						Exchange			
Oct 76	9.4	10	94.0	12.5	21	262.5	3.3	9	29.7	10.1	7	70.7
Nov 76	7.9	17	134.3	12.7	3	38.1	11.0	2	22.0	15.0	1	15.0
TOTAL		27	228.3		24	300.6		11	51.7		8	85.7
AVG	8.46			12.53			4.7			10.71		
			Turnback						Turnback			
Oct 76	4.7	26	122.2	4.2	9	37.8	5.1	11	56.1	3.8	9	34.2
Nov 76	5.7	14	79.8	4.0	8	32.0	1.5	2	3.0	1.5	2	3.0
TOTAL		40	202.0		17	69.8		13	59.1		11	37.2
AVG	5.05			4.11			4.55			3.38		

Table C38

Multivessel Standard Chambering Time

L&D 27 - After Guidewall Extension

	Main Chamber						Auxiliary Chamber					
	Up Direction			Down Direction			Up Direction			Down Direction		
Month	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.	Avg Time	No. Incl.	Avg × No.
Oct 76	23.9	35	836.5	20.5	18	369.0	15.4	11	169.4	16.3	23	374.9
Nov 76	22.1	13	287.3	24.2	21	508.2	16.4	5	82.0	16.4	8	131.2
TOTAL		48	1123.8		39	877.2		16	251.4		31	506.1
AVG	23.41			22.49			15.71			16.33		

NOTE: Chambering times shown above are the sum of the chamber entry and chambering times as provided by PMS.

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Daggett, Larry L
Sensitivity of base data in the analysis of lock capacity: a case study of Locks and Dam 26, Mississippi River / by Larry L. Daggett. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. ; available from National Technical Information Service, 1979.
107, [65] p. : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; HL-79-11)
Prepared for Office, Chief of Engineers, U. S. Army, Washington, D. C.

1. Lock and Dam No. 26, Mississippi River. 2. Lock capacity. 3. Locks (Waterways). I. United States. Army. Corps of Engineers. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; HL-79-11.
TA7.W34 no.HL-79-11